Grand Region ITS Telecommunications Study

FINAL

Prepared for:

MDOT

Michigan Department of Transportation
Grand Region Office

Prepared by:

Parsons Brinckerhoff Michigan, Inc.
500 Griswold Street, Suite 2900
Detroit, Michigan 48226
313.963.5760

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1.0 INTRODUCTION

1.1 Purpose

The Michigan Department of Transportation (MDOT) has been at the forefront in the use of Intelligent Transportation Systems (ITS) as a means of improving the efficiency of the region's transportation infrastructure. Deployments dating back to the 1970's, including freeway monitoring and advanced ramp metering systems, set the stage for development of the expansive advanced traffic management systems in place today.

MDOT is planning for significant expansion of the existing ITS traffic management network within the Grand Region. In addition, the Grand Region enjoys a strong partnership with the City of Grand Rapids and other local municipalities, which has yielded a multi-jurisdictional traffic signal system also planned for expansion. In order to strategically plan for accommodating this growth, MDOT has undertaken the Grand Region ITS Communications Study. The goal of the study is to effectively plan ITS communications network improvements to facilitate sustained system growth to meet existing and near-term needs, as well as to develop a strategy for addressing long-term requirements.

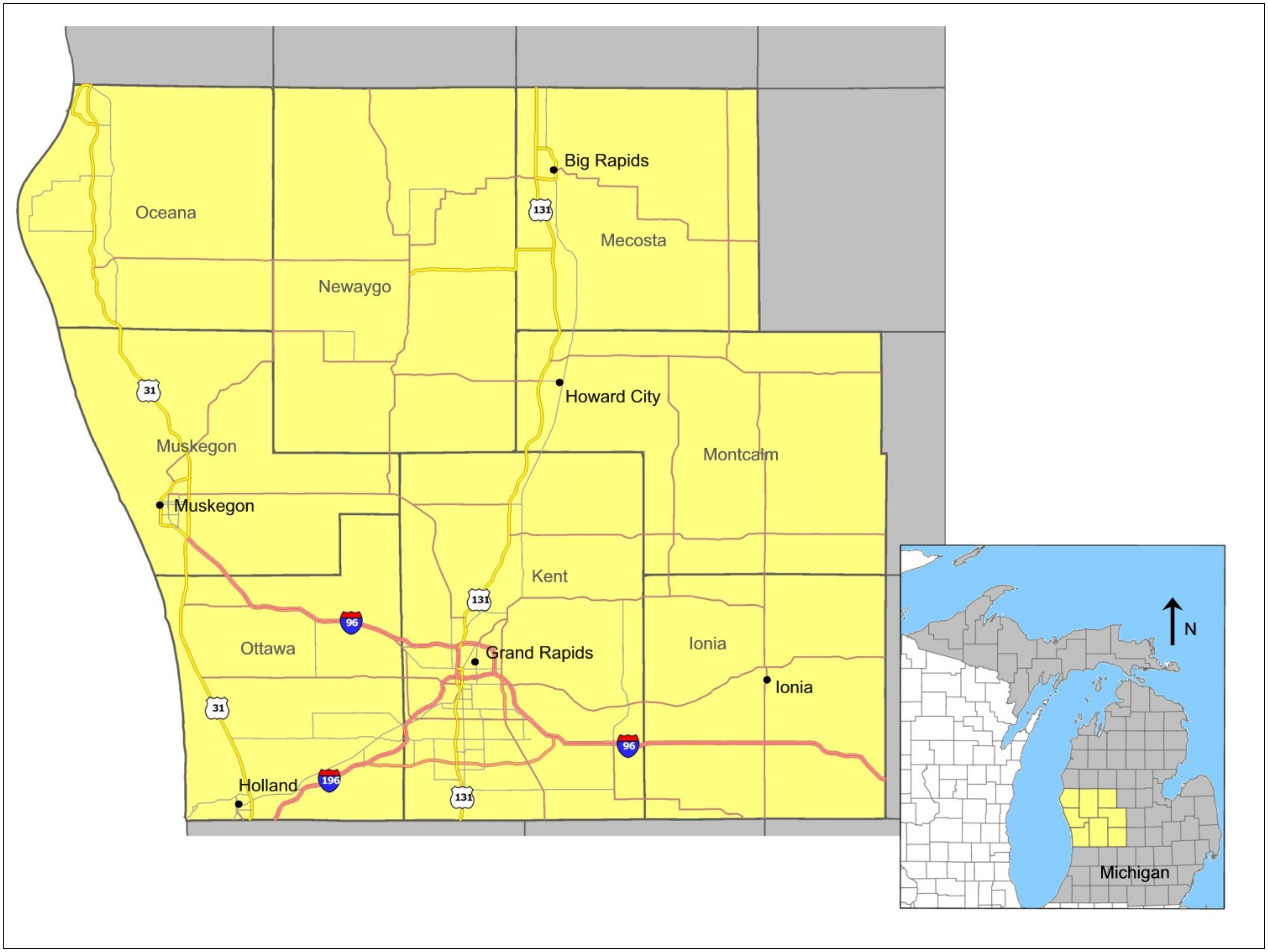
1.2 Study Area

The MDOT Grand Region ITS Communications Study covers the entire Grand Region area, comprised of Kent, Ionia, Mecosta, Montcalm, Muskegon, Newaygo, Oceana, and Ottawa Counties. The study area is depicted in Figure 1-1.

1.3 Report Methodology and Organization

Section 2.0 documents the inventory and capability analysis of the existing Grand Region ITS communications network throughout the MDOT Grand Region. Section 3.0 relays communications network needs and requirements associated with future expansion of the MDOT signal system and ITS program, as collected from MDOT and partner agency personnel. Available industry trends and technologies to meet MDOT and partner agency needs are provided in Section 4.0. Alternative solutions for upgrading the communications infrastructure are defined and compared in Section 5.0. Section 6.0 outlines a pilot program for testing possible technology solutions, and migrating to an eventual upgraded communications network. A summary of acronyms used throughout this report can be found in Appendix A.

Figure 1-1: Project Study Area



2.0 ANALYSIS OF EXISTING TELECOMMUNICATION SYSTEM

In the Grand Region, MDOT and its partnering agencies have an exceptional relationship which has developed into a network infrastructure that facilitates center-to-field (C2F) connectivity for each agency while providing center-to-center (C2C) connectivity for data/video sharing to multiple agencies. Understanding of the existing ITS and traffic signal infrastructure in the region was obtained through interagency coordination and site visits performed with the City of Grand Rapids, Michigan Department of Information Technology (MDIT) and MDOT staff. Information gathering meetings and field inspections were conducted to acquire knowledge about the current network conditions, configuration and devices. System documentation was also provided by MDOT and the City, which included a list of ITS devices, approximate locations and available system connectivity diagrams. Additionally, MDOT provided draft versions of the following reports for review and consideration as each contained valuable information which MDOT preferred to utilize and leverage where possible:

- Grand Valley Metro Council (GVMC) - Grand Rapids Metropolitan Area ITS Strategic Deployment Plan
- Grand Region's Regional ITS Architecture

Existing communication network diagrams and maps were developed using this information to illustrate communication techniques utilized and connectivity between field devices back to the Western Michigan Traffic Management Center (WMTMC). Once an inventory of the telecommunications infrastructure was complete, the system analysis was compiled through gaining a comprehensive understanding of the system's configuration, operational and functional uses, and other issues affecting the system.

Section 2.1 defines the existing infrastructure components and communications types that reside within the MDOT network. Section 2.2 explores how the infrastructure is currently being used – specifically what operations are being conducted throughout the network, and how much of the communications capacity is being used. Section 2.3 discusses the analysis performed on the MDOT communications network by pointing out strengths and weaknesses within its components and communications mediums.

2.1 Description of Existing Infrastructure

For the purpose of this report, the communications infrastructure for the MDOT network is categorized two ways: the infrastructure components and the physical communications medium which connect those components. In general, the components are the physical field devices that collect, send, and process data (e.g. Controllers, CCTV and DMS). The communication mediums and technologies enable data/video to be transported from field components and provide center-to-field connectivity. The geographic configuration and the communication linkages of data and video devices integrated into the MDOT system are depicted in Figure 2-1. A map of the existing City of Grand Rapids video and data devices in downtown Grand Rapids is provided in Figure 2-2.

Approximately 500 traffic signals within the City of Grand Rapids and neighboring communities are currently part of the interconnected signal system, which is operated and maintained by the City of Grand Rapids. The signal system is accessible at the WMTMC through the center-to-center communications link with the City. The following sections discuss the network components and communications by defining the different types of infrastructure within the existing MDOT network.

Figure 2-1: Grand Rapids Area Freeway Management System Devices

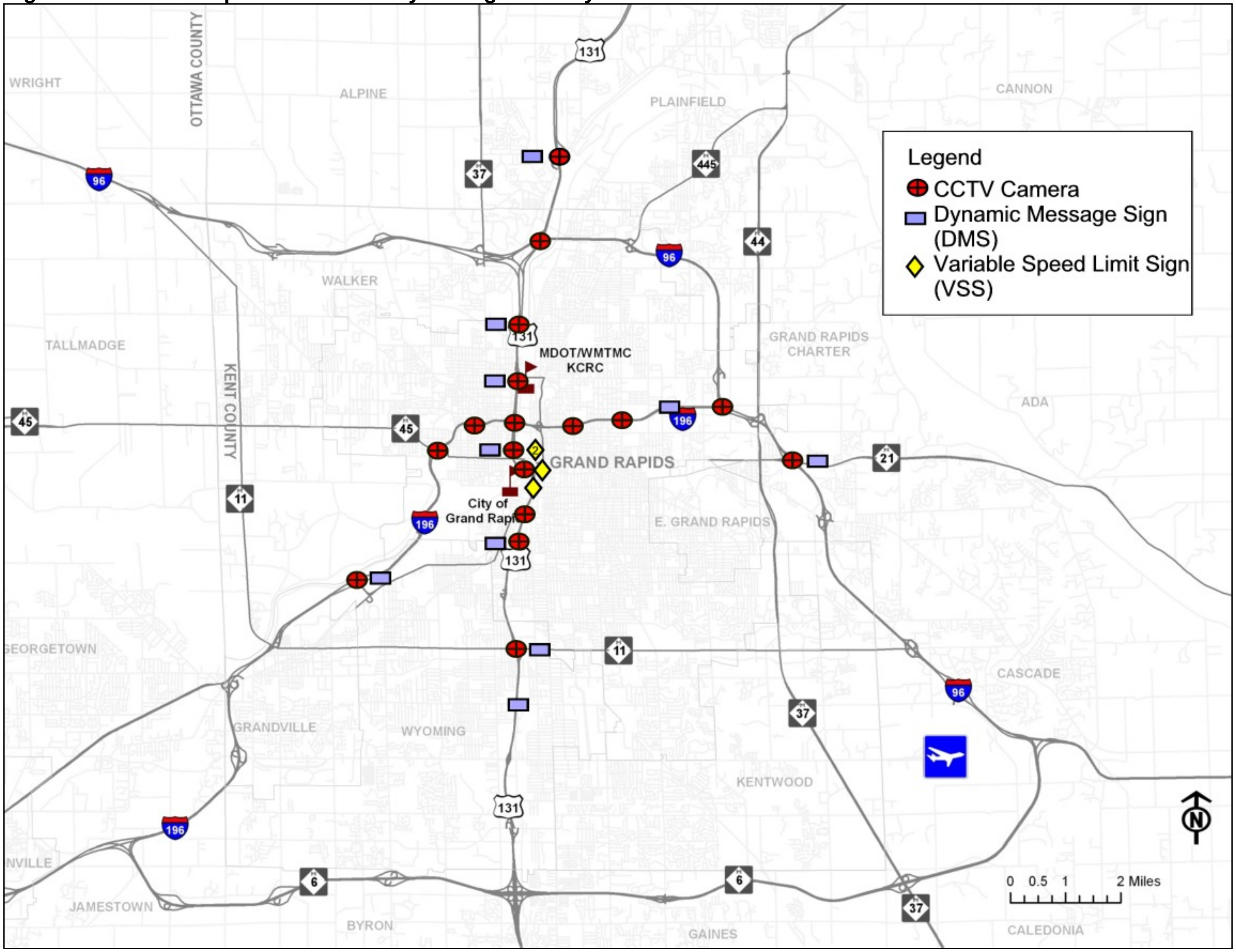
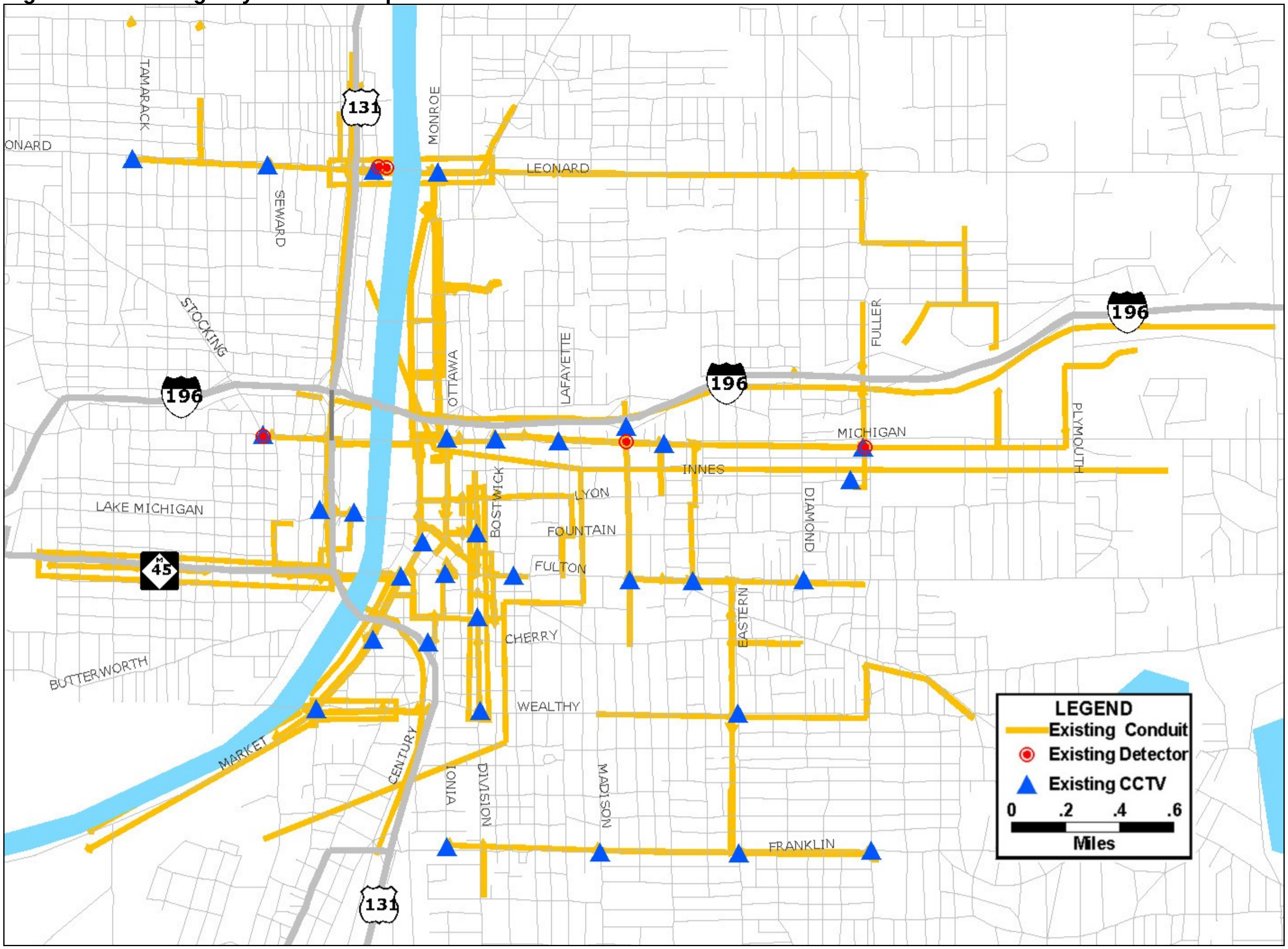


Figure 2-2: Existing City of Grand Rapids ITS Devices



The current communications infrastructure in the immediate Grand Rapids urbanized area consists of two largely independent systems:

- The MDOT Grand Region ITS network (hereafter referred to as the "MDOT network"), consisting of the infrastructure and devices as part of the freeway management system (including DMS, CCTV and mainline vehicle detection), and;
- The City of Grand Rapids arterial management network, consisting of the central multi-jurisdictional traffic signal system and arterial CCTV.

Figure 2-3 illustrates the high-level architecture of these two separate, inter-connected networks. While this report considers both of these inter-related networks in terms of future planning and overall architecture, the following sections provide an assessment of only the MDOT network.

2.1.1 Network Infrastructure Component Types

The MDOT telecommunications infrastructure is comprised of two types of physical infrastructure components: the traffic management center (WMTMC) and field devices. Each of these components is described below.

<u>Western Michigan Traffic Management Center</u>

The Western Michigan Traffic Management Center (WMTMC) is the core of the communications network and functions as the source and destination of data/video throughout the network. Traffic management systems for managing traffic, incidents and responses are housed at the WMTMC, which communicate with the field device components. There are direct communication links from the WMTMC to Field Devices, through fiber optic, T1 and dialup connections.

<u>Field Devices</u>

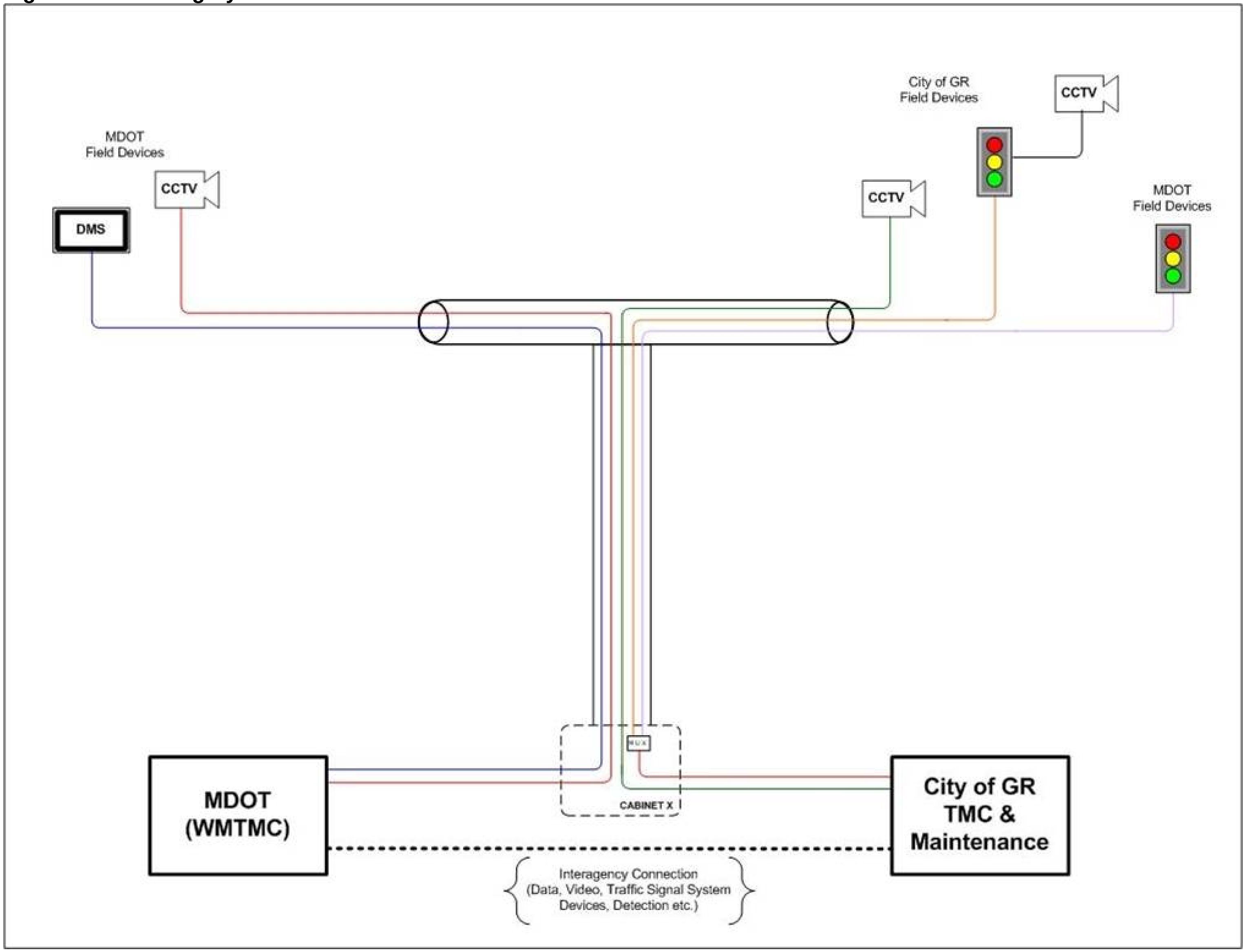
Field devices enable the various functions of regional traffic operations and management - and includes traffic signals, dynamic message signs (DMS), CCTV cameras, weather systems (anti-icing), variable speed signs and traffic detectors. This communications infrastructure component type is the actual device, as well as the communications and control equipment (e.g. ITS and traffic signal controllers, Ethernet switches, video codecs - encoder/decoder, protocol converters) typically located in a nearby field cabinet.

2.1.2 Network Communications Infrastructure Types

The MDOT telecommunication infrastructure has several types of communication technologies connecting network components. Fiber optic communications are the most widespread and are used within the network primarily as point-to-point connections between the WMTMC and the majority of the field devices, with some point-to-multipoint device configurations.

In addition the MDOT network utilizes wireless radio interconnect and dialup POTS connections to communicate to field devices within the region, such as traffic signals, DMS and weather systems (anti-icing).

Figure 2-3: Existing System Architecture



2.2 Description of Existing ITS Telecommunications Use

Currently in the Grand Region, MDOT does not utilize a consolidated central traffic management system known as an Advanced Traffic Management System (ATMS). Instead vendor-specific applications are utilized to manage each device type. MDOT uses the vendor-specific central control systems to transport video and device data to and from field devices on the telecommunications network. Due to the established center-to-center connectivity data/video is also shared bi-directionally with the City of Grand Rapids and Grand Rapids Police department.

The primary ITS device types currently within the system are CCTV cameras and DMSs, with the traffic signals on an isolated network. Fairly new video cameras are being used to transfer live images to the WMTMC, which outputs device control data (pan, tilt, and zoom) to the cameras. Video is viewed at the WMTMC as well as shared with other agencies and public websites such as MDOT's MI Drive. The system includes legacy and newer DMS installations, which communicate with controllers (vendor specific or 2070) that transmit message data to and from the WMTMC central control systems.

In addition, MDOT currently has six closed loop systems in the Grand Region outside of the Grand Rapids Metro area. Communication to the master controllers is done via fiber optic, wireless radio interconnect or dial-up POTS and occurs only on an as-needed basis for signal timing maintenance or manual timing plan changes, such as for special events. The closed-loop traffic signal systems currently in place in the Grand Region are operated and maintained by either MDOT's traffic signals unit or the City of Grand Rapids. All signals outside of the Grand Rapids metro area are maintained by MDOT or the local agency such as the City of Muskegon or the City of Grand Rapids. The approximately 350 signals in the Grand Rapids metro area are maintained by the City. Currently, while these signals are not operated by MDOT, they are accessible by the WMTMC via the center-to-center connectivity.

The number of existing ITS and traffic control devices managed by the WMTMC are presented below.

- 17 CCTV Cameras
- 10 Dynamic Message Signs (DMS)
- 4 Variable Speed Signs (VSS) and an Anti-icing System
- 10 Frost Tube Locations in Muskegon, Newaygo and Ottawa Counties (managed by TSCs)

2.3 Analysis of Existing System

The system analysis presented below discusses the strengths and weaknesses of the system as a whole. The analysis of specific communications network characteristics is presented below, including bandwidth, reliability, redundancy, maintainability, flexibility and expandability, and center-to-center communication capabilities.

2.3.1 Bandwidth

The existing MDOT communications infrastructure, configured and used as-is, presents no immediate or long-term concern for bandwidth utilization and capacity. This is primarily because the vast majority of the communications infrastructure is fiber optic cable and fiber-based communication technologies configured as point-to-point or point-to-multipoint connections from the WMTMC to field devices.

As further discussed in Section 4 – Technology Comparison, fiber optic cable and technologies have no theoretical limitations. The only limitation in this infrastructure type is the network appliance (and its overall capabilities) at each end of the physical cable. Furthermore, whole networks can operate successfully on a single fiber strand. A perfect example of this type of configuration and utilization is the core communications infrastructure in the Metro Region, which operates on four (4) fiber strands in a counter-rotating ring (two fibers (Tx/Rx) for each direction).

2.3.2 Reliability

In general, the MDOT telecommunication network operates reliably, and in the manner in which its proposed design is intended to function. Although current operational and functional needs are tolerably achieved, the overall day-to-day reliability of the system is affected by several factors such as system flexibility, maintenance and redundancy, each of which is further discussed below.

2.3.3 Redundancy

In the simplest form, redundancy is the process of duplicating critical components or elements to increase the overall reliability and availability of a system.

MDOT's center-to-field communication infrastructure consists of underground and aerial fiber runs, wireless radio interconnect and dial-up (POTS). The communication mediums do not contain any true form of redundancy on any links and therefore a failure (e.g. conduit/fiber cuts, wireless interference or service provider outages) along a link will result in total communication loss to the particular field device or multiple devices at certain locations. The point-to-point topology benefit of this network configuration is additionally the downside as the physical fiber optic cables are routed through the same conduit, cabinets and along the same single pathway back to the WMTMC. Therefore, under certain outages (e.g. conduit/fiber cuts, cabinets struck, etc.) total communication losses can occur to the whole system including center-to-center connectivity.

At the WMTMC the head-end systems and applications utilize multiple vendor solutions and equipment for traffic management. For instance, the video and DMS sub-systems are managed by different systems and applications, each of which is not setup in a redundant configuration. More significantly, the video system converts from digital back to analog where a single point of failure resides within the video codecs and analog matrix switching equipment.

Redundancy is an important system factor and can have an immense associated cost under certain implementations or topologies. Although systems may meet the user's needs and requirements, redundant elements should be introduced in a practical and cost effective way to establish a balanced system overall. Alternatives and options for the above discussed issues and/or concerns are furthered defined in the following sections of the report.

2.3.4 Maintainability

The following points provide a summary of maintenance for the current communications infrastructure:

- System maintenance is provided by a partnering agency versus being outsourced. The City of Grand Rapids staff is well educated with and is maintaining the existing communications infrastructure effectively.

- Presently the system's expertise is predominantly with fiber optic medium and within a point-to-point and point-to-multipoint configuration.

- At the present time MDOT's communications infrastructure is fairly moderate in size and complexity, however as the system continues to expand and build out with newer and more advanced technologies/topologies additional resources and/or training may be required.

2.3.5 Flexibility and Expandability

The current network configuration and topology is fully functional and meets the majority, if not all, of MDOT's near-term needs and requirements. In addition, the network is flexible enough as currently configured and utilized to meet long-term needs and requirements by continuing to expand in the same point-to-point or point-to-multipoint configuration techniques. However, doing so presents the same deficiencies discussed in this section and requires a significant amount of capitol investment to communicate to a single field device with little return on the investment (ROI).

MDOT's system expandability is not an issue of bandwidth availability or capacity, as discussed above in the bandwidth section, because there is more than adequate bandwidth available within the current fiber optic infrastructure to expand the MDOT network. The most significant constraints are the network appliances (or lack there of), configuration and topology. There are few elements of the communication infrastructure that will need to be replaced or modified in order to reconfigure and expand the current system. However, this depends on the level and type of expansions that will be made. For example, the addition of cameras, vehicle detection, and/or DMSs in certain locations throughout the MDOT Grand Region will require some new communication infrastructure deployments, while other locations will only require a few modifications to existing infrastructure. MDOT's expansion needs are more closely examined in the Needs Assessment portion of this study.

Technology advancements applicable to the ITS market have introduced enhanced communication technologies, and newer techniques have been identified for communicating with ITS field devices. Additionally and after the establishment of a solid core network backbone the ROI value and efficiency of communicating with field devices will be dramatically increased. Lastly utilizing newer communication appliances, topologies and techniques will improve numerous factors, including system robustness, flexibility, reliability, redundancy and expandability.

2.3.6 Center-to-Center Communications Capabilities

Center-to-center communication is an important component for MDOT and its partnering agencies within the Grand Region. MDOT already has an established communications link with the City of Grand Rapids TMC, the Grand Rapids Police department and the Kent County Road Commission (KCRC). However, under an updated network architecture center-to-center capabilities will still need to be considered. Additionally, the ability to accommodate the future desired center-to-center communication link with the statewide TMC envisioned in Lansing will also require consideration.

3.0 TELECOMMUNICATIONS NEEDS AND REQUIREMENTS

This section presents the needs and requirements associated with the MDOT telecommunication infrastructure. The needs and requirements were developed through input from the Michigan Department of Transportation (MDOT), as well as its partnering agencies. Input was collected at a stakeholder meeting held at the WMTMC in December, 2007. The primary purpose of this section is to define, and where possible quantify, use requirements for MDOT's telecommunication network in the future. A clear definition of the needs and requirements will be used to determine: a) if the current system will be able to meet future needs, and if not, b) what solutions can be applied to best fulfill the needs.

3.1 MDOT Expansion Needs

MDOT is looking to expand its current network coverage to include auxiliary control of the MDOT Grand Region signal system, additional ITS devices along freeways and trunkline arterial corridors, and Road Weather Information Stations (RWISs). Each of these subjects is covered in the following subsections.

3.1.1 Signal System Needs

Currently, approximately 100 MDOT signals are incorporated as part of the multi-jurisdictional traffic signal system maintained and operated by the City of Grand Rapids. Communication with these signals occurs via the City's communications network. Additionally, approximately 50 signals are currently part of independent closed-loop traffic signal systems throughout the region. Communication with these signals is handled using dialup POTS connections to a master controller, from which data is transmitted to other signal controllers via hardwired or radio-based interconnect.

In order to determine communications bandwidth requirements for future needs, a conservative assumption was made that any future backbone communications network must be able to carry data from all MDOT traffic signals within the Grand Region (a total of 374).

3.1.2 Traffic Management System Needs

Currently, design is already underway for ITS device expansion along freeways and trunkline arterials within the MDOT Grand Region. This planned expansion has made it necessary for MDOT to reevaluate the existing ITS network to determine its adequacy in supporting the expanded coverage areas as well as the most effective way to implement this expansion. As such, this section presents a quantified estimate of ITS device expansion, both in the near and long term, in order to analyze the existing system's capacity as well as determine what available solutions will best manage any shortfalls.

For the purpose of this study, MDOT has assumed a particular scale of ITS program growth within the immediate Grand Rapids metropolitan area to meet what it considers ideal operational coverage. The following ITS device installation interval assumptions were used in quantifying potential future bandwidth needs. These assumptions are conservative, but provide a worst case scenario when considering bandwidth needs.

- Future CCTV cameras will be installed in 1-mile intervals along freeways and trunkline arterials.
- Future Detector Stations will be installed in 1-mile intervals along freeways and at mid-block locations on priority arterials
- Future DMSs will be installed in 3-mile intervals along freeways.

- 1 to 5 RWIS Stations per County
- M-20 Flood warning system
- Drawbridge management system in Grand Haven

While MDOT is in the process of designing a system expansion along the I-96, I-196 and US-131 corridors during the course of this study, the current project calls for less density of field devices than the assumptions described above. For the purposes of this study, a full build-out of the maximum desired field device spacing is assumed along all freeways within the Grand Rapids Metropolitan area without existing coverage. In addition it is assumed that the existing system will be backfilled with upgraded equipment at the same device spacing. Table 3-1 summarizes the assumed additional miles of ITS coverage by route. Figure 3-1 illustrates the existing system, current expansion project areas, and future priority coverage areas.

3.1.3 Advanced Traveler Information System (ATIS) Needs

MDOT and region partners have identified a need for improved travel information as part of future ITS deployments. Advanced Traveler Information Systems (ATIS) refers to the various methods with which information is distributed to motorists. ATIS typically includes a combination of passive and active mechanisms for distributing traveler information, including:

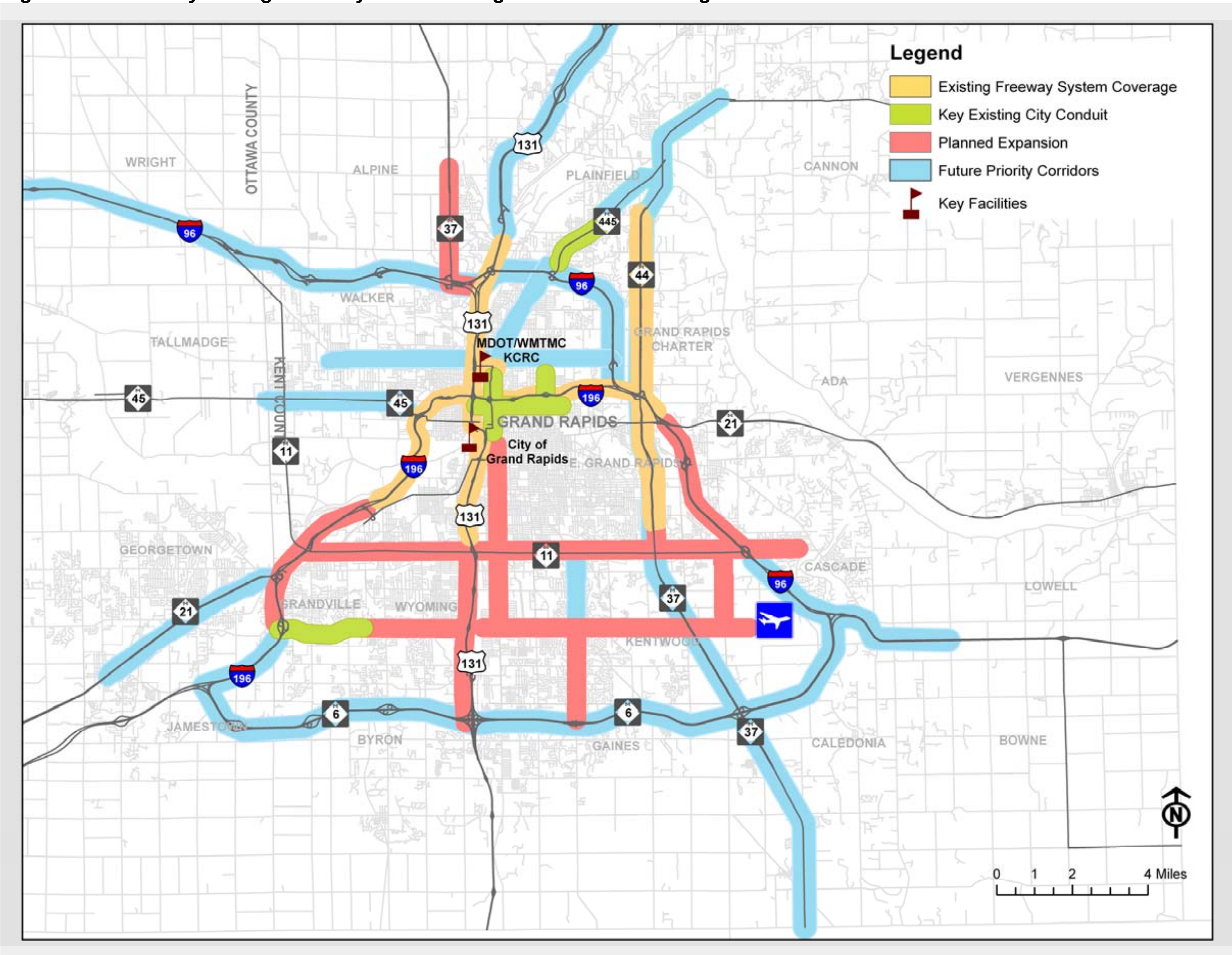
- Dynamic Message Signs (DMS)
- 511 Systems
- Web sites; email alerts and pre-trip planning
- Highway Advisory Radio (HAR)

Highway Advisory Radio (HAR) was identified as a potential ATIS technology that the region partners wanted to explore further to provide improved traveler information.

Table 3-1: Freeway System ITS Expansion Mileage Estimates

Freeway Management System Corridors		Mileage Estimate
Existing w/backfill	I-96	2
	I-196	9
	US-131	9
	Leonard Street	1
Proposed Expansion	I-196	5
	I-96	6
	US-131	5
	US-131BR	5
	M-11 (28th St)	14
	M-37	3
	M-44	2
	M-445 (Plainfield)	2
	44th Street	9
	Kalamazoo Ave	3
Future Priority	I-96	14
	I-196	4
	US-131	7
	M-6	20
	M-21	6
	M-45	5
	M-37	8
	Kalamazoo Ave	2
	Bridge Street	2
	44th Street	3
	Leonard Street	8
	Plainfield Ave	3

Figure 3-1: Freeway Management System Existing and Future Coverage



3.2 Partner Agency Expansion Needs

MDOT has an excellent relationship with its partner agencies in the region. All stakeholders in the WMTMC system have a commitment to continue this relationship and to advance the coordination throughout the region to meet the ever-changing needs of the traveling public of western Michigan. Consequently, a key component of this study was to gain input from MDOT's partnering agencies in order to best prepare the WMTMC communication network for future coordinated operations.

Using input from MDOT personnel, each of the key partner agencies were identified and contacted to participate in a stakeholder meeting. Representatives from the partnering agencies engaged in discussions with MDOT personnel, focusing on future needs (as far as 15 to 20 years) and coordination efforts that will require significant changes in communications infrastructure linkages.

Highlighted below is the partner agency input affecting the WMTMC communication network. In general, partner agencies indicated that their immediate data needs were not large. Several of the agencies did mention exchanging non-video operational data with MDOT (e.g., traffic flow, construction information, etc.). It is assumed that once communications linkages are made with the capacity to allow video exchange, the system linkage design will be flexible enough to allow for other data flow as well.

<u>City of Grand Rapids</u>

- 350+ traffic signals belonging to state, city, and surrounding counties are currently controlled and maintained via fiber and wireless interconnect from the City of Grand Rapids TMC.
- 20 CCTVs and 5 vehicle detection locations are also connected via fiber and wireless interconnect to the City of Grand Rapids TMC.
- City is currently sharing communications infrastructure with MDOT. Both agencies have access to all of the other's data.
- City assumes future data needs will continue to be provided through shared network resources.
- Center-to-center communication is needed between MDOT and the City.

<u>City of Wyoming</u>

- 53 traffic signals and 10 flashers are currently integrated into the City of Grand Rapids network.
- City is interested in enabling MDOT and the City of Grand Rapids to process incident responses.
- City is interested in having access to any implemented RWIS station data.
- City is interested in having access to summary data from future MDOT smart workzones.

<u>National Weather Service</u>

- Agency is interested in having access to any implemented RWIS station data.
- County specific weather data is available every two minutes and can be provided to any partner agency.

Ottawa County Road Commission

- OCRC is interested in having access to summary data from future MDOT smart workzones.
- No other immediate needs.

MDOT Statewide ITS Program Office

- Agency would like to implement a redundant backup facility in each region.
- Future plans include a statewide TMC in Lansing including a center-to-center interconnect with all regional TMCs.

MDOT Muskegon TSC

- Future drawbridge management system information may be shared with WMTMC.
- Agency is interested in having access to summary data from future MDOT smart workzones.
- No other immediate needs.

MDOT Howard City TSC

- Agency is interested in having access to summary data from future MDOT smart workzones.
- No other immediate needs.

MDOT Bureau of Transportation Planning

- Agency maintains a weigh-in-motion (WIM) system along I-96 that has no communication link and permanent traffic recorders (PTRs) throughout the region via phone lines.
- Agency desires to utilize MDOT telecommunications infrastructure to access PTRs.
- Agency is interested in having access to summary data from future MDOT smart workzones.
- No video needs at this time.

City of Muskegon

- City maintains 20-25 MDOT traffic signals with no interconnect.
- No other immediate needs.

Based on stakeholder input, no immediate needs for a dedicated communication network connection between the WMTMC and areas outside of the Grand Rapids metropolitan area were identified in the near future. However, consideration of mechanisms for facilitating future communication connections must be given during network planning.

3.3 Requirements for Communications Infrastructure

3.3.1 Requirements Gathering and Definition

System requirements need to be established to adequately identify and evaluate potential communications needs and possible solutions. The MDOT communication infrastructure requirements can be used throughout the system's life cycle to facilitate defining user needs, even though technologies used to meet those needs will continue to evolve rapidly. The system requirements compliment the needs discussed in sections 3.1 and 3.2 and provides specific objectives to be used in future system designs.

The requirements developed for this study are presented at a high level. These system requirements are related to the overall objectives of the system as a whole, rather than specific equipment/components. It is recommended that this document be used when deciding on detailed requirements after the System's functionality and technology tracks are more clearly defined.

Within the following requirements the "system" refers to the future communication network infrastructure within the MDOT Grand Region. The communication network is defined as the infrastructure required to facilitate transmission of data between the WMTMC, MDOT Partner Agencies, and existing/future MDOT field devices. The system includes existing and future: video encoders/decoders, fiber optic transceivers, radio system equipment, 2070 controllers, etc. The system does not include ancillary equipment that support communication hubs such as generators, servers, actual fiber optic or other cable lines, specific ITS field devices, or the network and central software system located within the WMTMC.

3.3.2 System Requirements

The following list of assumptions was used for the development of the system requirements presented in Table 3-2. These assumptions were also used for the development of the general needs, as well as identification and recommendation of deployment strategies for applicable technology solutions. The assumptions include:

- MDOT ITS device expansion will include backfilling coverage in existing areas, using the same expansion mileage rates assumed for future needs
- Existing ATMS software will be upgraded to be compatible with any upgrades made to the communication infrastructure
- Partner agencies will acquire video by tying into the MDOT system at strategically located nodes.
- System upgrades will build upon the existing system without making significant changes to the existing network topology, although additional nodes may be needed.

Table 3-2: MDOT Communications System Requirements

System Connectivity and Expansion	
1.	The System shall adhere to the following basic parameters: Open standards for communications and device/system level interfaces Interoperability between different vendor-based systems and sub-systems
2.	The System shall provide 99.5% operational and functional system availability.
3.	The System network infrastructure shall provide sufficient bandwidth allocation to integrate planned camera and ITS device expansion.
4.	The System network infrastructure shall be flexible and scalable enough to integrate rings and/or hub-spoke configurations that may be deployed for future MDOT or partner agency communications infrastructure.
5.	The System design shall take advantage of existing fibers or communications conduits that MDOT has been installing in conjunction with roadway improvement projects.
6.	The System shall provide communications to all traffic signal controller equipment to where current traffic signal operations and control are not effected.
7.	The network intertie between MDOT and the City of Grand Rapids shall be capable of transferring all network traffic between centers.
Video Requirements	
8.	Video within the System shall be NTSC standard.
Hardware Requirements	
9.	Communications equipment integrated into the System shall meet the industry standards for harsh environment installations.
10.	The System shall provide enhanced path-switching and restoration capabilities. Potential points of failure should be identified and distributed so as to be contained within a relatively small sub-region of the communication infrastructure.
11.	Cameras integrated within the System shall provide NTSC video.
12.	The wireless infrastructure within the System shall provide a high-degree of security in terms of cross-communication interference, encryption and intrusion detection.
Operational Requirements	
13.	The System shall allow camera control to be primarily a WMTMC function, which can be delegated to any of the agencies upon the agencies' request.
14.	System expansion shall maximize facilitation of future software enhancements and/or development.
15.	The System shall provide ease of maintainability throughout the ITS telecommunication infrastructure with specific emphasis on: • Network infrastructure management • Service provisioning and end-to-end service management • Configuration management • Fault isolation

4.0 TECHNOLOGY COMPARISON

This section provides a brief technology introduction and current state of the industry of the latest wired and wireless communication technologies and techniques, and a comparison of each in reference to how well they meet the needs of the Grand Region and its stakeholders. Numerous technologies were evaluated and investigated during the process of developing the telecommunications report, however only the technologies and features pertinent to the system will be discussed in this section, along with providing the necessary technology overviews and comparisons to accurately conduct an evaluation and assessment. Additionally, FHWA has developed an extensive report (*Telecommunications Handbook for Transportation Professionals – The Basics of Telecommunications*) that explorers and provides valuable information which complements this section of the report.

The next several sub-sections provide brief technology overviews, comparison parameters and comparison matrix for both wired and wireless telecommunication technologies.

4.1 Wired Technology Overview

Wired communication systems are defined by several elements, which include the distribution medium, distribution model, distribution scheme/configuration, and network topology. Each network element and the specific details related to the comparison and evaluation are depicted in Table 4-1.

Table 4-1: Wired Technology Overview

Network Element Details	Key Factors
Distribution Medium Distribution mediums are the physical cable/wire utilized to transport data from source to destination. Fiber optic cable has tremendous data bandwidth capacities over distances much greater than those possible in traditional copper-based mediums. Copper cable is limited to short-distance, low-bandwidth and low-cost applications. Copper conductor is sensitive to data throughputs at fairly low levels of bandwidth and distances.	Fiber-Optic Cable • Multi-mode • Single-mode Copper Cable • Twisted-pair • Co-axial
Distribution Models A data distribution model constitutes a physical and logical setup of simplex/duplex data transportation between source and destination. The selection of the most appropriate topology is the single most important consideration in any video/data/voice distribution network.	Analog Transmission • Amplitude modulation • Frequency modulation • Phase modulation Digital Transmission • Circuit switching • Packet switching

Network Element Details	Key Factors
Distribution Scheme / Configuration Distribution schemes/configurations relate to the different ways data is distributed over the network based on the needs of the data, users or services. The simplest form of data distribution is contained within a single LAN where every network is within the same subnet. Any other network topology configuration requires intelligent network appliances enable communication between networks by the form of routing. Multicasting is a bandwidth conservation and network traffic efficiency technology primarily intended to serve the same purpose as ITS does with traffic management for roadways and transportation engineering – just as agencies can't create more lanes to resolve congestion and improve safety - networks can't resolve bandwidth utilization with creating larger networks or circuits.	Protocols • Routing protocols • Routed protocols Features for data distribution: • IP multicasting • Multi protocol label switching (MPLS) • Open shortest path first (OSPF) • Virtual local area network (VLAN) • Virtual private network (VPN) • Quality of service (QoS)
Network Topology Network topologies are representative of the physical layout and interconnections in a data distribution network. Network topologies are extremely important considerations in the implementation of any kind of network, primarily because most of the communication protocols have been specified for optimal operations on specific network topologies. The two key categories of topologies fall under LAN (Local Area Network) or WAN (Wide Area Network) topology: WANs including enterprise networks, metro-wide and regional networks are built on topologies that are a combination and extension of the core LAN configurations.	LAN topologies • Bus/linear • Mesh (full/partial) • Ring • Star • Hybrid WAN topologies • Peer-to-peer • Ring • Star • Mesh (full/partial) • Tiered

4.1.1 Wired Technology Comparison Parameters

In order to complete a comparison and evaluation of wired technologies as they relate to applications, systems and user requirements, comparison parameters were established. Table 4-2 presents a description of each parameter and relevant details.

Table 4-2: Wired Technology Comparison Parameters

Parameters	Details
Bandwidth Capacity and Provisioning	Bandwidth capacity is a measure of the size and speed of data that can be transferred over the network, and is a direct characteristic of the type of data flowing through the network. Based on the data rates, networks are typically classified as: • High-speed – (Multimedia, remote business applications, storage area networks (SANs) or databases) • Low-speed – (Serial or SCADA applications) Bandwidth provisioning – is the ability of adding bandwidth capacity to the communications distribution network.
Bandwidth Utilization	Bandwidth utilization is the measure of the communications data throughput or the effective capacity of the network that is utilized by the communications traffic. The most common measures of this parameter are: • Bandwidth efficiency – a measure of how effectively competing traffic flows can be maximized through the overall bandwidth capacity of a network. • Bandwidth allocation – is the capability to dynamically assign bandwidth resources for communication between users/devices on the network. • Bandwidth granularity – is a measure of the size of bandwidth that cab be allocated for dedicated communication.
Communications Data Characteristics	This parameter deals with the transmission characteristics of the network data, and it differentiates the network data into two main categories: • Uniform traffic – is characterized by a steady stream of traffic over the extent of the communications duration. • Bursty – is an uneven flow of traffic over multiple time periods due to the inherent nature of data or the effect of user access on the network.
Quality of Service (QoS)	Quality of Service reflects the elimination of latencies in data communications, enablement of reliable data delivery, and improvement of quality of data delivery. QoS becomes an important consideration in the presence of the following factors: • Shared network infrastructure where there is bandwidth and other network resource contention between multiple users/devices. • Sensitivity of the communications data to delivery delays and jitter. • Large-scale networks (specifically packet-switched) with numerous data hops across routers can lead to delays and consequently degrade QoS.
Telecommunication Traffic Engineering (TE)	TE is the use of statistical techniques to predict and engineer the behavior of networks. TE has traditionally been performed in IP networks, in its simplest form it is basically how packets are routed between two endpoints in a network. In MPLS, TE is enhanced because it provides both the layer 2 and layer 3 traffic engineering capabilities. The important components of TE are: • Bandwidth management, allocation and dynamic provisioning • Setting up Classes-of-Service and rules of data delivery • Network performance monitoring with the highest level of granularity • Dynamic configuration of network interfaces • Traffic modeling and capacity planning

<table>
<tr><th>Parameters</th><th>Details</th></tr>
<tr><td>Network Restoration and Protection</td><td>Network restoration is the self-healing characteristic of the network, whereby a break in the network path triggers an automatic re-routing of traffic to the destination. Protection is the mechanism that enables restoration of the network. The following are the important characteristics of network restoration and protection:
Network restoration time – a measure of the time it takes to establish an alternate route around the failed link or path and re-establishment of data propagation.
Network restoration scheme – the feature of the network to re-establish alternate routes around the failed link or path. Self-healing networks perform restoration automatically based on the intelligence built into the network infrastructure.
Control Plane – is a logical network layer that oversees the continuous and efficient operations of the data layer.</td></tr>
<tr><td>Network Management</td><td>Network management is the set of Operations, Administration and Maintenance (OA&M) activities that can be performed for the entire network. There are two distinct hierarchical layers of network management, which include:

Element Management System (EMS) – As the term suggests this system enables management of individual network elements or devices in the distribution network. It provides the management of capabilities and functionalities of the devices with features such as:
Resource utilization
Element performance monitoring
Element fault monitoring
Network Management System (NMS) – NMS is a level higher than EMS and takes into account the entire network OA&M features. It retains functionality such as:
Traffic management between network elements
Performance monitoring
Fault reporting/analysis
Overall network resource management
Traffic engineering and QoS management
Management of network restoration schemes
Management of control planes if they exist
Communications with EMS and their management
Network security and intrusion detection</td></tr>
<tr><td>Multicasting</td><td>Multicasting is the simultaneous distribution of the same data to a select group of subscribers over a shared network environment. It is similar to broadcasting or one-to-all transmission with the difference that data is transmitted to a set of subscribed users only and not broadcasted to all users in the network. Users have the ability to subscribe and un-subscribe to the data transmission on a real-time basis. The important parameters for multicasting are:
Multimedia services such as video, digital TV, radio, etc. are the most common data types in multicasting
Communications distribution technology and hardware must support multicasting protocols to enable multicasting
Traffic engineering and QoS are important considerations in revenue-based multicast services</td></tr>
</table>

Parameters	Details
Integration	Integration in a network is the ability to interface with different types of data subsets at the edges of the core communications backbone. It is generally a measure of the following: • Relative ease of physical interfaces and configuration/re-configuration • Relative cost of adding the interfaces and integration
Cost Factors	The following are the four most important cost considerations in large-scale communication distribution networks: • Cost of bandwidth provisioning – Costs related to the setup and upgrade of the core capacity of a network and often measured as relative cost-per-bandwidth for different distribution technologies. • Cost of network OA&M – A measure of the ongoing costs associated with the operations, administration and maintenance of a network. • Cost of convergence or multi-service integration – Costs associated with the integration of delivery of multiple data types and services over the same distribution infrastructure. • Cost Efficiencies – A direct measure of the ability to gain maximum efficiencies in bandwidth utilization for revenue-generating/business-critical communications distribution over a network.

4.1.2 Wired Technology Comparison

Table 4-3 presents the various communication technology alternatives with the comparison parameters that were described in the previous section. Although this study considered alternatives in addition to those listed below, the selection of the following alternatives was based on the following criteria:

- Whether technology is generally proven / widely implemented
- Whether products are available from multiple vendors
- Suitability for metro-scale networks
- Cost practicality

Table 4-3: Wired Technology Comparison Matrix

Communication Distribution Technologies	Description	Bandwidth Capacity		Bandwidth Utilization			Communications data characteristics
		High /Low Speed Networks	Bandwidth Provisioning	Bandwidth efficiency	Bandwidth allocation	Bandwidth granularity	Uniform Traffic/Bursty Traffic
Traditional SONET/SDH	A TDM based communications distribution where the entire core network and the edge interfaces are based on SONET/SDH format of communications	High bandwidth capacities Ideally suited for either high-speed network or a large-volume low-speed network but not a combination of both.	Fairly difficult Does not support intermixing of low-bandwidth links with high-bandwidth links	Very low bandwidth efficiency due to the rigid SONET container sizes	Ideal for dedicated communication links with pre-determined bandwidth guarantees Static bandwidth allocation with limited granularity No capabilities of dynamic allocation	Limited by SONET channels with very limited granularity within channels Limitation also set by ADM (Add/Drop Multiplexer) interface configuration. Re-configuration fairly difficult	Ideal for uniform or steady-flow traffic Not suited for bursty traffic due to rigid bandwidth granularity
Traditional IP	A packet-switched communications distribution where the core network and edge interfaces operate on the traditional IP routing and switching model	High bandwidth capacities enabled via Gig-E and 10 Gig-E transportation protocols Suitable for intermixing of high-speed and low-speed traffic	Relative ease, dependent on network topology. For example, fairly easy in a protected network or a hub-spoke topology	High bandwidth efficiency due to the inherent nature of packet-switched delivery	No inherent capability of dynamic bandwidth allocation No ability to setup VPNs for dedicated connections	Very high bandwidth granularity	Ideal for bursty traffic
SONET-over-MPLS	A result of Next-Gen SONET evolution, this transport system establishes SONET connection circuits over an MPLS packet backbone	High bandwidth capacities Capable of intermixing high-speed and low-speed traffic	Same as Traditional SONET because the underlying communications backbone is still SONET based	High bandwidth efficiencies due to the reduction in rigidity by MPLS and Next-Gen SONET protocols such as GFP and VC	Capabilities for dynamic bandwidth allocation Supports VPNs	Better than Traditional SONET but not as granular as IP networks	More suitable for bursty traffic than Traditional SONET
IP-over-MPLS	An IP packet delivery model where the network backbone operates on the MPLS distribution scheme	High bandwidth capacities enabled via Gig-E and 10 Gig-E transportation protocols Highly capable of intermixing high-speed and low-speed traffic	Same as Traditional IP	Very high bandwidth efficiencies, due to the introduction of dynamic virtual connections model of MPLS	Capability for dynamic bandwidth allocation Capability for dynamic bandwidth reservation Full support for VPNs and dedicated links	Same as Traditional IP	Suitable for both bursty and uniform traffic

Table 4-3: Wired Technology Comparison Matrix (Continued)

Communication Distribution Technologies	Description	QoS	Traffic Engineering (TE)	Network Restoration and Protection		Network Management	
				Network restoration time/Scheme	Control Plane	Element Management System	Network Management System
Traditional SONET/SDH	A TDM based communications distribution where the entire core network and the edge interfaces are based on SONET/SDH format of communications	High QoS per dedicated SONET channel No capability of dynamic QoS and CoS (Classes-of-Service)	No capabilities for Traffic engineering	Robust network restoration scheme but possible via redundant fiber link that is part of a bi-directional path-switching configuration Restoration time up to 50 ms (millisecond) Re-setup of failed links or nodes time consuming	Absent	Present Features limited to performance monitoring of nodes and limited configuration options with no traffic engineering	No inherent capabilities for overall network management on top of element management
Traditional IP	A packet-switched communications distribution where the core network and edge interfaces operate on the traditional IP routing and switching model	No inherent QoS QoS enabled through complex routing protocols	No capabilities for Traffic engineering	Restoration scheme dependent on topology In large-scale mesh networks, re-routing is shared across the network and individual node or link failures easy to fix Restoration time in the order of 2 to 3 seconds and dependent on routing technologies	Control plane intelligence limited to per-hop basis	Present Features hardware and vendor specific	No inherent capabilities for overall network management on top of element management
SONET-over-MPLS	A result of Next-Gen SONET evolution, this transport system establishes SONET connection circuits over an MPLS packet backbone	Capability of dynamic QoS and CoS	Full capabilities for Traffic engineering Capabilities for user separation	Restoration enhanced by MPLS integration Similar or better restoration times than Traditional SONET	Full-fledged control plane with end-to-end path computation capabilities	Present Features hardware and vendor specific	Provides inherent capability for full-fledged end-to-end network management with traffic engineering
IP-over-MPLS	An IP packet delivery model where the network backbone operates on the MPLS distribution scheme	High QoS capabilities QoS enabled through virtual connection model of MPLS Capability of dynamic QoS and CoS	Full capabilities for Traffic engineering Capabilities for user separation	Robust restoration scheme enabled by MPLS Capabilities for determining alternate paths in advance Restoration times competitive to SONET restoration	Full-fledged control plane with end-to-end path computation capabilities	Present Features hardware and vendor specific	Provides inherent capability for full-fledged end-to-end network management with traffic engineering

Table 4-3: Wired Technology Comparison Matrix (Continued)

Communication Distribution Technologies	Description	Multicasting	Integration		Cost Factor			
			Relative Ease	Relative Cost	Cost of Bandwidth Provisioning	Cost of network OA&M	Cost of Multi-service Integration	Cost Efficiencies
Traditional SONET/SDH	A TDM based communications distribution where the entire core network and the edge interfaces are based on SONET/SDH format of communications	Not available	Low	High	High	High	N/A	Low
Traditional IP	A packet-switched communications distribution where the core network and edge interfaces operate on the traditional IP routing and switching model	No inherent capabilities for multicasting Multicasting enabled through special routing technologies and protocols	Medium	Medium	Low	Medium	Medium	Medium
SONET-over-MPLS	A result of Next-Gen SONET evolution, this transport system establishes SONET connection circuits over an MPLS packet backbone	Provides a robust platform for implementing multicasting Traffic Engineering enabled via MPLS ensures efficient and effective multicasting	High	Low	High	Low	Low	High
IP-over-MPLS	An IP packet delivery model where the network backbone operates on the MPLS distribution scheme	Provides a robust platform for implementing multicasting Traffic Engineering enabled via MPLS ensures efficient and effective multicasting	High	Low	Medium	Low	Low	High

4.2 Wireless Technology Overview

Wireless communications systems are defined by several elements, including the wireless equipment, radio frequency, frequency modulation, and network topology. Each network element and the specific details related to the comparison and evaluation are depicted in Table 4-4.

Table 4-4: Wireless Technology Overview

Network Element Details	Key Factors
Wireless Equipment	Radios • Analog • Digital Transceivers Master Stations • Repeaters • Antennas • RF Cables • Support Structures
Radio Frequencies Frequencies are categorized on the basis of frequency magnitude. Following are the important categories of RF Spectrum: • Ultra High Frequency (UHF, 300 to 3000 MHz) – Generally used for TV broadcasts • Super High Frequency (SHF, 3 to 30 GHz) – Typically used by wireless LANs, mobile devices and microwave devices	RF Spectrum • Licensed (protected) • Unlicensed (un-protected) Microwave Spectrum • Typically between 3 GHz to 300 GHz • Less susceptible to atmospheric conditions than longer wavelengths • Have greater bandwidth or data carrying capacity compared to other (lower) RF spectrums Spread Spectrum • Primarily developed to overcome intentional or unintentional interference and for the overall security
Frequency Modulation Modulation is the process of varying amplitude, frequency or phase of a carrier or signal wave in relation to another wave or signal. In digital wireless communications, it is often required to use the same channel by more than single user. This requires collaborative access methods that will allow use of the same physical medium or channel by multiple users.	Analog modulation • Amplitude • Frequency • Phase • Pulse Digital • Time division multiple access (TDMA) • Frequency division multiple access (FDMA) • Spread spectrum multiple access (SSMA)
Network Topology Wireless Network topologies are equivalent to the LAN network topologies discussed previously under Wired Technology Overview, in Section 4.1.	

4.2.1 Wireless Technology Comparison Parameters

In order to complete a comparison and evaluation of wireless technologies as they relate to applications, systems and user requirements, comparison parameters were established. Table 4-5 presents a description of each parameter and relevant details.

Table 4-5: Wireless Technology Comparison Parameters

Parameters	Details
1. Bandwidth	Bandwidth is the measure of the data carrying capacity of the wireless transceiver. It is a function of various parameters of the radio system, but the most important being the radio spectrum or the frequency of operation. There exists a direct relationship between frequency and bandwidth; higher the frequency greater the bandwidth and vice versa. This relationship is more prominent in analog wireless systems, while in digital radio system there are other important factors too such as modulation schemes.
2. Range	Range is the maximum distance of effective communication between wireless transceivers. Effective implies communication within the specified bandwidth and reliability. Wireless range is also a function of the frequency of operation, with an inverse relationship, where higher frequencies define lower ranges and vice versa. The physical parameters of a radio system such as transmission power, receiver sensitivity, etc. also affect the range of a wireless system, and while greater power results in a greater range, there exists a practical limit to the power of a transmitter and are controlled by the FCC. There are several constraints that come into play some of them regulatory and some of them operational. In analog wireless systems, greater ranges also introduce other requirements such as amplification. Antennas play an important role in increasing the range of a radio system but also introduce cost and complexity considerations.
3. Line of Sight factors	Most radio systems on the market operate in line-of-sight or near-line-of-sight conditions. Frequency is again an important factor determining this parameter, with lesser frequencies having greater penetration capacity. The usual counter to a non-line-of-sight condition is to deploy the transceivers along alternate paths or through intermediate hops (radio links) that enable near-line-of-sight or line-of-sight conditions.
4. Reliability	Reliability is a measure of data loss of the wireless transmission, and is often determined by the modulation schemes and communication protocols of the radio system. Other physical aspects of the transmitter and the antenna also affect the reliability factor. While cost plays an important role in any aspect of the radio system, it is more prominent when it comes to reliability.
5. Protection	A very critical determination in the design of a wireless system is the decision to employ licensed or unlicensed frequencies. Unlicensed frequencies are those that FCC has allocated for IEEE 802.11 mode of wireless communication and are typically in the 2.4 and 5 GHz range. While each has its pay-off in terms of cost and complexity, the critical factors to consider are: • Does the criticality of the data communication warrant FCC protection in the form of licensed frequencies? • Are issues related to cross-communication, interference, and saturation all strongly associated with un-licensed frequencies, important enough to consider cost and effort associated with licensed frequencies? • Range and reliability can both be increased substantially within the licensed spectrum as there are no stringent regulatory limits to the power of the radio transmission as is in the case of unlicensed spectrum
6. Security	Security becomes an important consideration in the case of unlicensed frequencies as they are more prone to malicious attacks and more open to hacking and disruptions. With licensed systems, proprietary modulation schemes play an important role in deterring the security breaches and disruptions.

Parameters	Details
7. Integration	Integration is an important consideration when deciding between analog radio systems and digital radio systems, as it determines the ease with which the wireless data can be interfaced with its wired counterpart or customer premise devices / systems. Within the digital world of wireless systems, most of all the radio vendors provide Ethernet interfaces and therefore does not become an important constraint or limitation for integration.
8. Complexity of Deployment	Deployment of any kind of wireless system is preceded with a propagation study, path analysis, interference analysis and the like. The comprehensiveness of these studies and their impacts gain significance when deciding between unlicensed spectrum and the licensed spectrum. There are various other tangibles that affect the design and deployment of a wireless system that are completely independent of the technology such as – terrain, weather conditions, hazardous conditions, etc.
9. Cost	Cost in the deployment of a wireless system is a direct product of the complexity of deployment, and is influenced by all the factors defined above. Typically range, bandwidth, reliability and protection are the most important determinants of the cost of a wireless system, and are equally important in design as they are in the selection of the radio equipment.
10. Maintenance	Maintenance of wireless systems is an equally important product of design as it is of the actual product selection, as there are several variations that can be applied in the deployment of a radio system such as – deployment site, configuration, antenna height, etc., which can ultimately affect the maintainability of the system in the long-run. In terms of the product selection there is a stark difference in the ease of maintainability with regard to an analog radio system versus a digital radio system, with the digital system being much easier to maintain in all the major aspects of its performance. Within the digital radio products, reliability and protection plays a major influence on the maintenance aspect with higher reliability and protected systems requiring lesser maintenance.

4.2.2 Wireless Technology Comparison

Table 4-6 presents the various wireless communication technology alternatives with the comparison parameters that were listed in the previous section. The selection of the following alternatives was based on the following criteria:

- Whether technology is generally proven / widely implemented
- Whether products are available from multiple vendors
- Suitability for metro-scale networks
- Cost practicality

Table 4-6: Wireless Technology Comparison

Wireless Communication Technologies	Description	Bandwidth	Range	Line of Sight Factors	Reliability	Protection
Digital Unlicensed Wireless System (IEEE 802.11)	A radio system that modulates digital signals on to the carrier frequency typically using the TDD modes of modulation	• Inherent multiplexing • Low bandwidth, due to constraints inherent in the modulation schemes and the power output of the transmitters • Typically in the range of 3 Mbps to 11 Mpbs	• Low ranges, influenced by antenna size, point-to-point or point-to-multipoint configurations and other site factors • Typically goes up to a maximum of 2 - 3 miles	• Typically Line-of-Sight operations • Sensitive to cross-communication interferences	• Low to Medium • Reliability is often increased by creating multiple paths of signal propagation	• Operate on unlicensed frequencies allocated by the FCC (typically in the 2 and 5 Ghz range) • No FCC protection implies greater exposure to cross-communications interference, jamming, and no legislative support
Digital Licensed Wireless System (Including Public Safety Systems)	A radio system that modulates digital signals on to the carrier frequency typically using the FDD forms of modulation	• Inherent multiplexing • High bandwidth capability based on exact modulation scheme, wireless communication protocols and physical characteristics of the radio system • Can go as high as 150 Mbps	• High ranges due to less constraints on power output, also influenced by antennas and configurations • Typically operate in the 10 to 20 mile ranges but can go higher based on product specifications and complexity	• Line-of-Sight operations and Near-Line-of-Sight operations • Very less impact of interference	• High reliability often represented by four or six 9's (99.9999 or 99.999999%) reliability • Reliability is typically a factor of the communication protocols such as SONET radios vs. Ethernet radios. SONET radios have greater degree of reliability • Reliability is often increased by redundant radio transceivers	• Typical operations in licensed frequencies • High degree of reliability is a direct consequence of protected operations • Typically, critical data communications utilize this medium of wireless communications because of the legislative and other benefits • Licensing introduces administration hassles and added costs
Digital Spread-Spectrum Wireless System	A digital radio system that utilizes frequency hopping and the FHSS forms of modulation to transmit digital signals	• Inherent multiplexing • Low bandwidth capabilities due to low frequency band allocations typically in the 900 MHz range • Typically under the 1 Mbps range	• Low to medium ranges, which are possible due to the low frequency of operations • Can go as high as 10 to 20 miles based on product specifications	• Also supports Non-Line-of-Sight operations • Very less sensitive to interferences due to frequency hopping modulation scheme	• High reliability • Typically less reliable and less spectrally efficient	• Does not require licensing or protected operations • But frequency of operations must confirm to the allocated bands by FCC

Table 4-6: Wireless Technology Comparison (Continued)

Wireless Communication Technologies	Description	Security	Integration	Complexity of Deployment	Cost	Maintenance
Digital Unlicensed Wireless System (IEEE 802.11)	A radio system that modulates digital signals on to the carrier frequency typically using the TDD modes of modulation	• Security features are constantly evolving with emerging IEEE standards and have now reached a fairly decent level for commercial use • Typically security configuration not easy and requires subject-matter expertise	• Easy integration with all typical interfaces being Ethernet capable	• Design – high complexity • Installation – medium complexity • Configuration – medium complexity • Integration – low complexity	• Design – medium cost • Equipment – low cost • Installation – low cost • Configuration – low cost • Integration – low cost	• High maintenance due to less reliability and greater number of devices
Digital Licensed Wireless System (Including Public Safety Systems)	A radio system that modulates digital signals on to the carrier frequency typically using the FDD forms of modulation	• Medium to High security due to proprietary and complex modulation schemes • Higher security is also a product of the typical protected mode of operations for FDD radio systems	• Easy integration with all typical interfaces being Ethernet capable	• Design – high complexity • Installation – medium complexity • Configuration – medium complexity • Integration – low complexity	• Design – medium cost • Equipment – high cost • Installation – medium cost • Configuration – medium cost • Integration – medium cost	• Low to medium maintenance based on deployment of redundant transceivers
Digital Spread-Spectrum Wireless System	A digital radio system that utilizes frequency hopping and the FHSS forms of modulation to transmit digital signals	• High security, which is a direct product of frequency hopping and FSSS mode of modulation	• Easy integration • Typically serial data interfaces • New generation also have Ethernet capable interfaces	• Design – medium complexity • Installation – low complexity • Configuration – medium complexity • Integration – medium complexity	• Design – medium cost • Equipment – low cost • Installation – medium cost • Configuration – medium cost • Integration – low cost	• Low-to-medium maintenance

4.2.3 Wireless Frequency Availability

This section discusses the differences between licensed and unlicensed frequency bands. For more detailed information about wireless communication refer to Section 4.2 Wireless Technology Overview. Each frequency band whether licensed or unlicensed has known pros and cons. Listed below is a brief description of the microwave spectrum, attributes about each band, and some of the associated risks and benefits.

The microwave spectrum, licensed and unlicensed, is usually defined as electromagnetic energy ranging from 1 GHz to 1000 GHz, however the most common applications are within the superhigh frequency (SHF) range of 3 GHz to 30 GHz.

Licensed spectrum

Licensed spectrum equipment typically uses Frequency Division Duplexing (FDD), where data transmission and reception is on distinctly separate frequencies. Therefore full-duplex data transportation occurs, simultaneously in both directions, which allows the maximum bi-directional data throughput. By its nature FDD is less prone to interference, as each radio operates in its own licensed frequency. A primary advantage of FDD is when symmetrical traffic is required for both the uplink and downlink. Table 4-7 illustrates some of the known risks and benefits of the licensed spectrum.

Unlicensed spectrum

Unlicensed spectrum equipment typically uses Time Division Duplexing (TDD), although FDD products are also available, where data transmission and reception share a single frequency. Therefore half-duplex data transportation occurs, transmit in one direction then stop and receive. Consequently this will negatively affect the maximum bi-directional data throughput, as it actually emulates full-duplex communication over a half-duplex communication link. However, the advantage of TDD is when asymmetrical traffic is required or desired of the uplink/downlink. Table 4-8 illustrates some of the known risks and benefits of the unlicensed spectrum.

The most common advantages of the licensed spectrum are it offers a more stable operating environment because it’s relatively free from interference, guarantees constant bandwidth while achieving superior distances over its counterpart. Though, strong advantages of the unlicensed spectrum are the quickness and simplicity of deployment and lower equipment costs. The “which technology is better” has been a long standing debate and while this discussion could go on forever in favor of either or, the point to keep in mind is each band has a specific purpose and fulfills a particular application in the wireless telecommunication industry. Licensed or unlicensed wireless communication links must be properly evaluated based on specific criteria for each location and link. Listed below are some examples of that criterion:

- What type of data will be transported?
- What is the importance of the data?
- What amount of bandwidth is required?
- How much data will be transported in either direction (asymmetrical or symmetrical)?
- What is the range/distance required of the link?
- What level of link availability, reliability and security is required?
- What are the propagation study, path and interference analysis results?
- What is the budget for this link?

Table 4-7: Licensed Spectrum Risks and Benefits

Risks	Benefits
A license is required by the FCC for use of a protected spectrum • Cost associated for spectrum access • Administrative and regulatory requirements more complex	A license is required by the FCC for use of a protected spectrum • Providing interference-free operation • Provides superior quality of service • Providing a legal recourse to issues
The time to implement is longer • Due to cost and time associated with obtaining a license	Assured levels of system bandwidth, performance, availability and reliability accomplished by a combination of: • Higher power levels • Lower frequencies • Better signal propagation characteristics • Antennas and; • Superior range capabilities
Less spectrally efficient • Due to use of one entire frequency for transmission and one entire frequency for reception	Ideal for regional type backhaul communication links • Where links are transporting data between network nodes (transportation of numerous device data at one time)
The capitol costs are typically more	Traditionally equipment is high-end, carrier grade • Offering higher quality for reliability and environmental conditions

Table 4-8: Unlicensed Spectrum Risks and Benefits

<table>
<tr><th>Risks</th><th>Benefits</th></tr>
<tr><td>A license is not require by anyone
Providing no legal recourse to issues
Provides limited quality assurance and service</td><td>A license is not require by anyone
Little or no cost for spectrum access
Low administrative and regulatory requirements</td></tr>
<tr><td>There is no guarantee of interference-free operation
An unlicensed system could be deployed and later (next day, week or year) interference could render it degraded or even completely useless
In a system with multiple co-located equipment (e.g., backhaul and distribution), it is even possible for the equipment to interfere with each other</td><td>The time to implement is shorter</td></tr>
<tr><td>Federally mandated, controlled and limited power levels
Lower power levels can drastically hinder signal propagation and range capabilities</td><td>Ideal for last mile type communication links
Where links are transporting data between a device or devices and a network node (co-located sites with CCTV, DMS, RTMS, VSLS, etc)</td></tr>
<tr><td>Frequency coordination/planning is more difficult
(e.g., trying to manage several channels at one location plus avoid other channels in use by others)</td><td>Provides better spectrum efficiency (applicable to TDD not FDD)
Due to use of one entire frequency for transmission and reception</td></tr>
<tr><td>No guarantee for continuous system bandwidth, performance, availability and reliability
Not guarantee to provide long term reliable communication links</td><td>The capital costs are typical lower</td></tr>
</table>

Based on the outcome from the above type of criteria and evaluation performed for each communications link, the determination processes for a licensed or unlicensed communication links will definitely be clear cut. The selection process must take into account the actual project budget and evaluate any trade-offs prior to finalizing a design. Section 6.0 of this plan further analyzes the different wireless technologies recommended, while evaluating the system needs and requirements and ultimately illustrating the components and design considerations.

5.0 ATIS AND HAR SYSTEM FEASIBILITY

The essence of Intelligent Transportation Systems (ITS) is the gathering of traffic data, converting it to useful information and providing it to users and operators of the network. MDOT and region partners have identified improved dissemination of travel information as an critical function, and are seeking expanded means to do so. Advanced Traveler Information Systems (ATIS) refers to the various methods with which information is distributed to motorists. This section describes different ATISs available and evaluates the feasibility of deploying highway advisory radios (HAR) based on the Grand Rapids Metropolitan Area ITS Strategic Deployment Plan (SDP) recommendations.

The ATIS summarized here are:

- Dynamic Message Signs (DMS)
- 511 Systems
- Web sites; email alerts and pre-trip planning
- Highway Advisory Radio (HAR)

5.1 Dynamic Message Signs (DMS)

DMS (or Variable Message Signs, "VMS") have proven to be both effective in accident reduction and popular with the public. In Houston[1] real-time travel time information posted on DMS influenced drivers' route choice. Eighty-five (85) percent of respondents indicated that they changed their route based on the information provided (of this 85 percent, 66 percent said that they saved travel time as a result of the route change, 29 percent were not sure).
Overall, drivers were primarily interested in seeing incident information and travel time information. The Table 5-1 shows the percentage of respondents that perceived positive benefits from specific types of DMS alerts.

Table 5-1: DMS Alerts

Type of DMS Alert	Percentage of Respondents who Perceived Positive Benefits
Incident alerts	93%
Freeway travel times	82%
Real-time road work advisories	81%
Future road work advisories	70%
Severe weather information	67%
Amber alerts	61%
Special event information	31%

In Japan[2], real-time alternative-route travel time information posted on dynamic message signs contributed to a 3.7 percent divergence rate during periods of congestion, saving detoured motorists an average of 9.8 minutes per vehicle.
DMS are the principle method by which agencies such as MDOT have to communicate with drivers. In general drivers are unaware of the operating agency. An exception to this is service

[1] http://ops.fhwa.dot.gov/publications/travel_time_study/houston/houston_ttm.htm

[2] Evaluation of Route Comparison Information Boards on Hanshin Expressway Atsush, Abe, et al. 5th World Congress Conference on ITS. Seoul, Korea October 1998

patrols. However DMS are popular and effective when operated in a manner that keeps the messages both relevant and credible.

Implementation of DMS requires both careful placements to ensure a balance between providing the driver with sufficient distance to achieve diversions yet remain close enough to the congestion to be relevant. In addition, operating procedures that provide messages that do not go stale are needed. Daily reminders of regular congestion couched in generic terms are not considered helpful. Travel times and incidents are the regularly found to be the most often requested data. This choice of incidents and travel time as the most popular data types is shared with all other ATIS distribution mechanisms.

5.2 511 Systems

511 systems, phone-based traveler information systems accessed by dialing 511, are becoming ubiquitous throughout the country as the mobile phone market nears full market penetration. A study in Kentucky[3] showed that 94 percent of all respondents indicated that they were very satisfied with the answers and information that operators provided. In the San Francisco Bay Area 92.3 percent of users surveyed were satisfied with 511, and in Montana, 90.3 percent[4]. MDOT has recently completed a Statewide Strategic Plan and feasibility study to determine if implementing a 511 service in Michigan in feasible. The plan concluded that while 511 systems can be very effective and are viewed positively by the public, the availability of real-time information in Michigan is not yet robust enough to warrant full 511 deployment.

5.3 Web Services

MDOT has deployed the MI Drive website as a means to support pre-trip planning by providing near real-time traveler information, including travel speeds, incident warnings, construction alerts, and even video webcasting via the internet. While ATIS web services are able to offer the greatest depth of information to motorists, they are generally limited in their utility to pre-trip planning for those users with access to a computer or mobile web services at that time.

Currently, the MI Drive site for the Grand Rapids area allows users to view video images from the region's CCTV cameras along I-96, I-196 and US-131, and provides construction alerts. With an expanded vehicle detection capability in the region, travel speeds could be added to this site in the future.

The utility of such sites is improved as they become integrated with 511 systems and start to provide alerts to inform drivers of worse than normal conditions on specific routes at particular times. This value is particularly enhanced when travel times are provided. Web-based information systems are widely utilized as part of an overall ATIS strategy, but given their limitations are typically just one tool used in conjunction with other active and/or passive in-route technologies.

5.4 Highway Advisory Radio (HAR)

Highway advisory radios (HAR) were first used on the George Washington Bridge in 1940. They typically broadcast on a dedicated frequency in the AM band with a tunable range between 1 and 6 miles. Due to Federal Communications Commission (FFC) requirements HAR cannot broadcast entertainment and are restricted to traffic information.

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[3] http://www.itsdocs.fhwa.dot.gov/jpodocs/repts_te/14307_files/14307.pdf

[4] http://www.deploy511.org/docs/511%20Guidelines%20Version%203.0.pdf

These radios are typically programmed by an operator using a customized telephone. This phone is used to call the sign that records the telephone message and then plays it repetitively. A significant issue that reduces the efficiency of HAR is that drivers are reluctant to change radio channels to listen to repetitive travel information. This reluctance leads to the use of Dynamic Message Signs (DMS) to alert drivers to listen to a HAR. The problem with this is that the same message can be displayed on the DMS obviating some the HAR need. HARs cannot provide directional information and thus if a driver were to keep listening in many cases the message listened to is information concerning the opposite direction. This problem is made worse in complex intersections where drivers are going in multiple directions.

There are also technical problems with HARs. HARs tend to be on AM channels as these were abandoned by commercial broadcasters as the sound quality was poor. Although there are FM-based HARs these are limited to rural areas as they can interfere with commercial broadcasts in cities. Although HARs can provide more information than a DMS they are now often used in areas where the information is limited to a closed area, including airports, tunnels and large parks.

The following reference is from a recent FHWA report; Communicating with the Public Using ATIS During Disasters: A Guide for Practitioners FHWA-HOP-07-068 April, 2007

> “In a small pilot project at the Phoenix International Raceway held during the spring 2005 NASCAR races, Maricopa County DOT (MCDOT) rented additional portable HAR units from a private vendor. The goal was to disseminate different messages to both incoming and outgoing traffic throughout the course of the weekend events. The HARs performed well in testing, but once the event began, MCDOT found that the HARs became inoperable due to radio interference from the sheer number of communications devices operating at the same time in the area. Interference came from radio communication being used by radio and television stations, by internal communications of the Raceway and public agencies, and by increased use of commercial radio by travelers, causing the HAR to be unsuccessful. Contributing to the problems with HAR is the fact that it is licensed as a secondary user under the guidelines established by the Federal Communications Commission (FCC), which means HAR transmission cannot interfere with primary users such as commercial broadcast stations. In addition, the FCC limits antenna height to approximately fifty feet, which limits its broadcast quality. Deployment in rural or suburban areas tends to be more successful than in urban areas, where structural interference is a problem.”

Several urban locations have used permanent HAR stations to broadcast work zone driver information messages. Permanent HAR’s are not very effective since drivers do not always correlate their location with the project location. Portable trailer mounted units have had great success the past few years when integrated into construction projects with high driver interest due to traffic impacts. Timely accurate messages have brought very positive comments from drivers. Portable HAR’s are currently used in many work zones around the country where permanent systems are not available and provide flexibility to go where the work operation is. Portable temporary DMS are also available and can display the same message in the immediate area of the construction. HAR has a range of 1 to 6 miles, and depending on the location of the construction site, drivers may need more advanced notice than this to make a travel decision or change routes. More advanced warning is better disseminated through a web service or 511 system.

The technical difficulties and the limitations of the HAR, together with the many new and more effective and directed methods for information dissemination, lead to the conclusion that HAR should not be recommended in a new ITS project. The exception would be for a closed and rural area where there are fewer conflicting road directions and no interference from commercial stations. Temporary portable HAR systems may be considered for work zone projects with high driver interest due to traffic impacts.

6.0 ANALYSIS OF TELECOMMUNICATION ALTERNATIVES

The purpose of this section is to examine the technological recommendations, define the bandwidth requirements, present network configuration solutions identified for addressing system deficiencies and meeting future needs based on the discussion topics from the previous sections.

The following sections define the proposed telecommunications infrastructure, present network loading and configuration alternatives, identify the comparison criteria used to evaluate the alternatives, and provide the resulting analysis along with a conclusion outlining recommendations. The recommendations are further detailed in the following sub-sections, where specific aspects of migrating and deploying the recommended infrastructure are discussed.

6.1 Telecommunication System Baseline Recommendations

The foundations of any wireline ITS telecommunications infrastructure are the conduit plan and the distribution medium, which transports data from source to destination. The partnership between MDOT and the City of Grand Rapids has resulted in construction of an expansive in-ground fiber-optic network encompassing a significant portion of the freeways and arterials in the urban center of Grand Rapids. This fiber-optic network is continually undergoing expansion, including the installation of conduit and fiber-optic cable along 44th Street during the summer of 2008.

Given the significant investment to date in conduit installation, it is recommended that the core ITS communications network for the region leverage this investment and utilize fiber-optic cable as the primary media. However, the existing network is not hierarchical in nature, which will limit ultimate carrying capacity and expandability of the system. Therefore, it is recommended that before migrating to newer technologies and techniques on the existing fiber-optic cables that a defined communications backbone be developed – utilizing existing or proposed fiber-optic cable.

While fiber-optic cable represents the medium to facilitate communications, network protocol and topology define the language and structure of the network. Based on discussions with MDOT and partner agencies, it is recognized that the new ITS network will be Internet Protocol (IP)-based, as IP has become the standard of the technology industry due to its flexibility and ease of network management and maintenance.

6.2 Bandwidth Requirements

The purpose of the bandwidth analysis is to estimate the communication bandwidth (load) requirements to support the existing, planned, and future ITS system elements. The findings of this bandwidth analysis will give MDOT an estimate of the bandwidth required to support the successful build-out of the proposed ITS system and current design, for the purposes of designing near-term system capacity and ultimate scalability. The analysis is based upon the planned and future ITS devices and center-to-center requirements. Table 6-1 outlines the assumptions of specific bandwidth estimates used to analyze the proposed network build-out loadings. Specifically, the bandwidth differences between the MPEG-2 and MPEG-4 video encoding represent one of the most significant decisions to be made by MDOT when upgrading the network. The clarity of the video will be lessened by encoding the video more, which is typically done to meet bandwidth constraints. Additionally the use of multicasting within the video network will considerably reduce the overall bandwidth utilization.

Table 6-1: Bandwidth Estimate Assumptions Per ITS Device Type

ITS Device	kb	Mb
Video & Control Data (MPEG-2)	6144	6
Video & Control Data (MPEG-4)	3072	3
Traffic Signal	128	0.125
Detection	128	0.125
VMS	128	0.125
RWIS w/camera (MPEG-4)	3200	3.125

The bandwidth analysis estimates a highest use scenario, which assumes that each device is constantly communicating and that all traffic will pass through the same point on the network at the same time, therefore illustrating the largest communications pipe required, in order to enable "right-sizing" of the network linkages during future detailed design activities. Tables 6-2 and 6-3 outline the existing, proposed and future ITS devices and their bandwidth calculations.

6.3 Network Configuration Alternatives Analysis

While existing investments and industry trends have largely defined the network medium, topology and protocol recommendations, the partnership between MDOT and the City of Grand Rapids to construct and maintain communications infrastructure necessitates consideration of the optimum network configuration before further significant investment is undertaken. As such, one of the primary objectives identified during the early stages of this project was to define "how to share" and utilize the proposed IP-based telecommunications infrastructure and network. The following sections illustrate the alternatives identified, the evaluation criteria used to differentiate them, and the results of the evaluation.

6.3.1 Network Configuration Alternatives

Three technically feasible configuration alternatives were identified for the development of the MDOT network, combining a range of technologies and techniques aimed at addressing the system deficiencies and needs identified in Sections 2.0 and 3.0, respectively. The alternatives identified are intended to provide a range of solutions to MDOT, leveraging existing systems and infrastructure to meet near and long-term needs. Table 6-4 provides a brief summary of each alternative. Figures 6-1 through 6-3 illustrate each network architecture.

Table 6-2: ITS Devices per Expansion

Freeway Management System Corridors		Mileage Estimate	Cameras	Detection	VMS	Traffic Signals	RWIS w/camera	Total ITS Devices by Expansion Type
Existing w/backfill	I-96	2	2	2	1	75	3	128
	I-196	9	9	9	3			
	US-131	9	9	9	3			
	Leonard Street	1	1	1	1			
Proposed Expansion	I-196	5	5	5	2	100	3	231
	I-96	6	6	6	2			
	US-131	5	5	5	2			
	US-131BR	5	5	5	2			
	M-11 (28th St)	14	14	14	5			
	M-37	3	3	3	1			
	M-44	2	2	2	1			
	M-445 (Plainfield)	2	2	2	1			
	44th Street	9	9	9	3			
	Kalamazoo Ave	3	3	3	1			
Future Priority	I-96	14	14	14	5	100	3	298
	I-196	4	4	4	2			
	US-131	7	7	7	3			
	M-6	20	20	20	7			
	M-21	6	6	6	2			
	M-45	5	5	5	2			
	M-37	8	8	8	3			
	Kalamazoo Ave	2	2	2	1			
	Bridge Street	2	2	2	1			
	44th Street	3	3	3	1			
	Leonard Street	8	8	8	3			
	Plainfield Ave	3	3	3	1			
Total ITS Devices (by Type)			157	157	59	275	9	**657**

Table 6-3: ITS Device Bandwidth Calculations

Totals	Cameras	Detection	VMS	Traffic Signals	RWIS w/camera	Using MPEG-2	Using MPEG-4
ITS Devices (by Type)	157	157	59	275	9	1031.5	560.5
Bandwidth (by Type)		19.625	7.375	34.375	28.125		

Table 6-4: Network Configuration Alternatives

Alternative	Description and Features

Alternative 1:
 	
Shared Ethernet (End-to-End)
 	
No Segmentation
	• Existing infrastructure upgraded to Ethernet
	• Shared end-to-end
	    o Conduit
	    o Fiber
	    o Network appliances
	    o Single IP subnet
	• Each agency connected to network core/backbone
	• Interagency center-to-center (C2C) connection is provided via network core/backbone

Alternative 2:
 	
Shared Ethernet (End-to-End)
 	
Virtual Segmentation
	• Existing infrastructure upgraded to Ethernet.
	• Shared end-to-end
	    o Conduit
	    o Fiber
	    o Network appliances
	• Segmented IP subnet/network for each agency
	• Each agency's devices are virtually segmented by subnet/VLAN at each network appliance
	• Each agency has its own connection to network core/backbone
	• Interagency center-to-center (C2C) connection is provided via network core/backbone or TMC

Alternative 3:
 	
Segmented Ethernet (End-to-End)
 	
Physical Segmentation
	• Existing infrastructure upgraded to Ethernet
	• Shared end-to-end
	    o Conduit
	    o Fiber or buffer tube (where applicable)
	• Segmented IP subnet/network for each agency
	• Each agency's devices are physically segmented via its own network appliance and fiber (where applicable) end-to-end
	• Network (core/backbone) provides transport services for multi-agency devices
	• Each agency has its own connection to network core/backbone
	• Interagency center-to-center (C2C) connection is provided via TMC

Figure 6-1: Alternative 1 Network Architecture

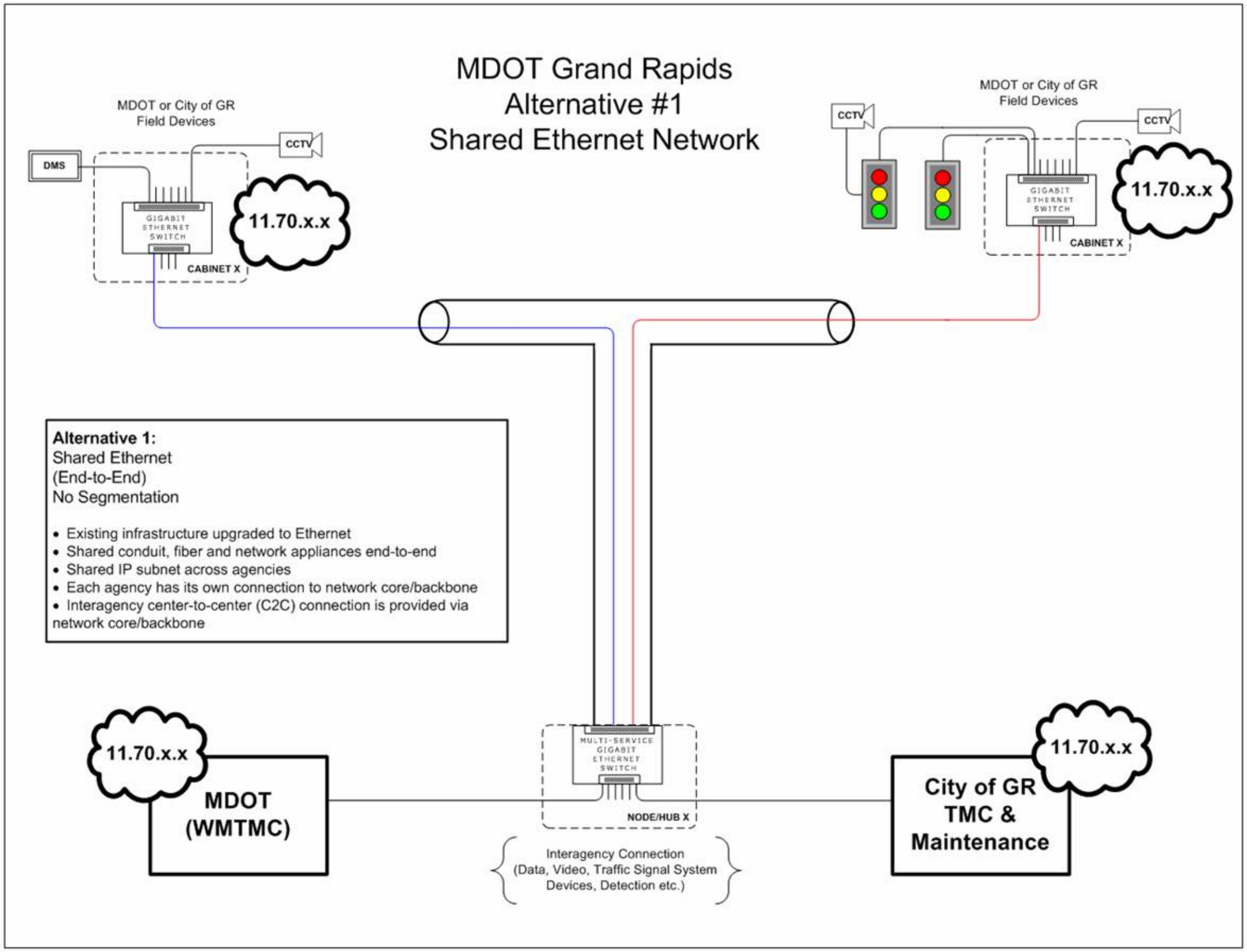


Figure 6-2: Alternative 2 Network Architecture

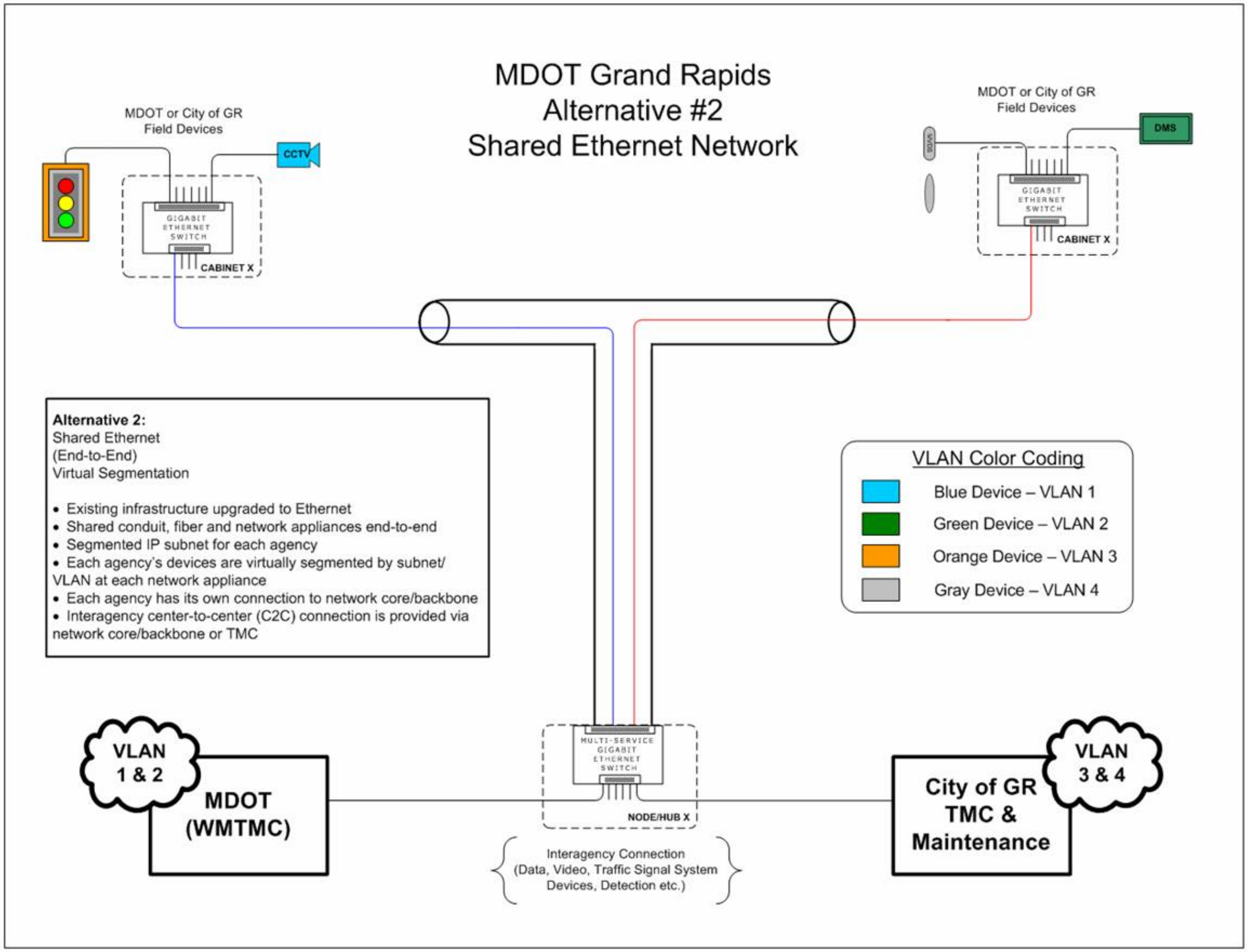
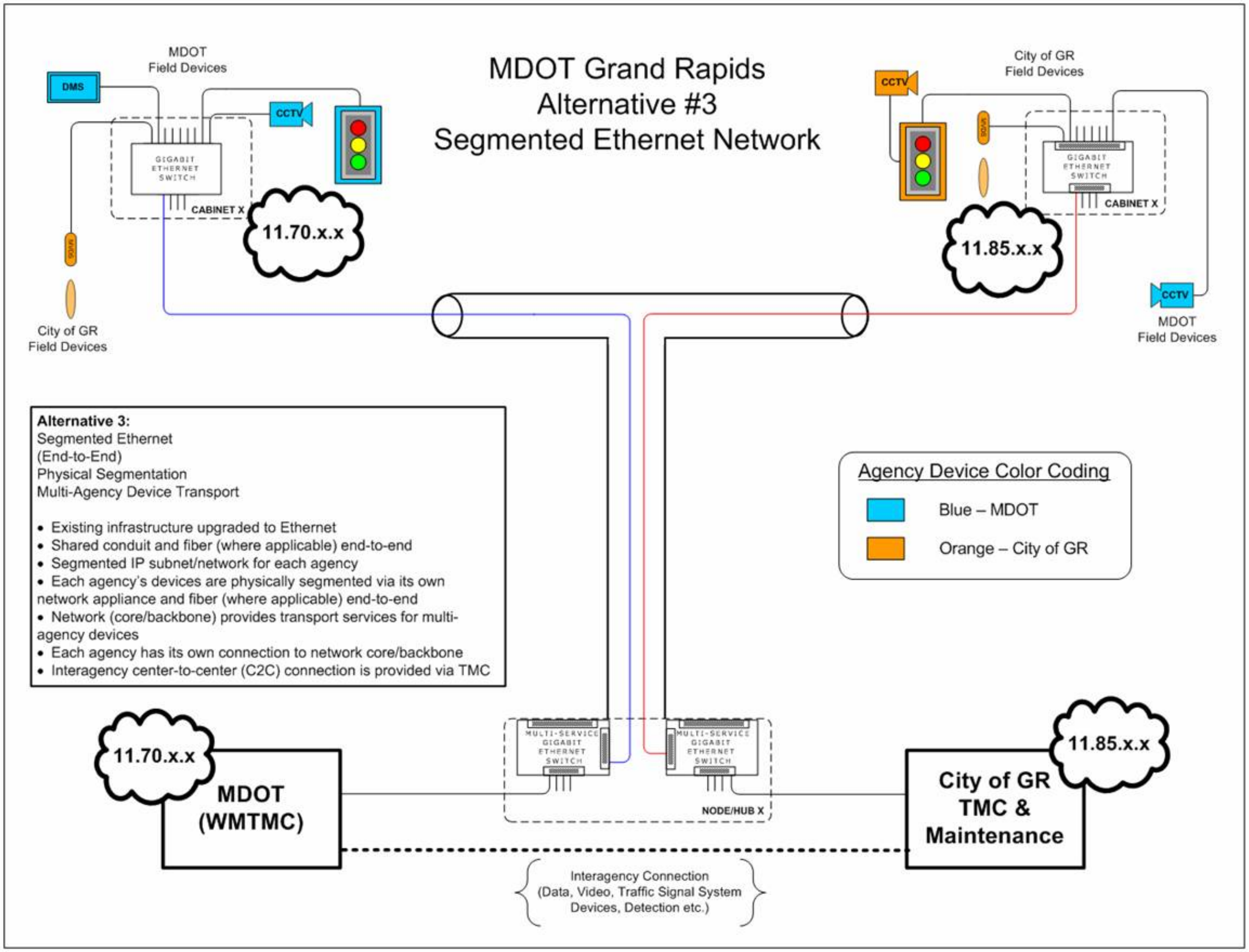


Figure 6-3: Alternative 3 Network Architecture



6.3.2 Comparison Criteria

Each alternative was assessed against the identified user needs and requirements and the following factors or criteria were additionally considered before deciding upon a preferred alternative.

Ability to Address Needs and Requirements

Section 3.0 assesses needs identified by MDOT and partner agency personnel for this study, and translates those into system requirements. Each of the alternatives are evaluated as to their ability to meet these needs and system requirements, both existing and future.

Maintenance and Operations

Another labor and cost factor that will affect MDOT is the recurring maintenance and operational costs associated with the particular technology and deployed configuration. Each of the alternatives are evaluated to determine how much labor would be required to keep the upgraded system up and running. This will include costs associated with the number of maintenance personnel required, labor hours, and training; as well as other recurring operational costs.

Security

Each technology may provide different levels of security. As such, each alternative is evaluated to compare the general level of security strengths and weaknesses associated with the solution. Ultimately, MDOT personnel will need to apply specific agency security standards to the technologies and alternatives analyzed in this study to more accurately compare advantages and disadvantages.

Redundancy

Redundancy within communications infrastructure is increasingly important as emphasis is being placed on continued public-sector operations – especially in emergency situations. While certain technologies do facilitate more redundant communications networking, redundancy is dependent on the particular topology of the system. A determination must be performed as to whether the whole system or application is actually mission-critical, versus if it can be categorized/prioritized into mission-critical, non-critical or not-required segments and network elements.

Flexibility and Expandability

A well balanced telecommunications system tends to demonstrate capabilities to address overall effectiveness, reliability and resiliency. In being flexible and expandable a communications system should utilize an “open architecture” and not be dependent upon a single solution or manufacturer. Therefore by its characteristics these types of designs and systems provide the ability to seamlessly use newer technologies, keeping up with current and future system demands and broaden its coverage area.

Bandwidth Management and Efficiency

Bandwidth load management and performance capabilities are very important factors in determining the present needs to support the system as well as the future needs and expansion capabilities.

6.3.3 Alternatives Evaluation

Table 6-5 presents a summary of the ranking of each alternative for each of the comparison criteria, including an overall ranking of how well the alternative compares against the others overall.

As illustrated in the table, Alternative 3 was found to be the most advantageous for MDOT. It best meets the needs and requirements identified by MDOT and partner agencies while providing the most robust network obtainable. Listed below are some additional advantages of Alternative 3:

- Migration to industry-standard IP/Ethernet systems technology, thereby reducing long-term maintenance costs and providing an expanded base of qualified maintenance personnel.
- Ease of center-to-center (C2C) interconnections including Lansing and Metro Region, which are likely to be Ethernet/IP-based.
- Enhanced C2C capabilities, including ease of data and video sharing with partnering agencies using in-kind IP-based networks.
- Ease of integration of new statewide system software, which is likely to be on an IP-based platform.
- Leverages cost sharing of conduit and fiber infrastructure, while simplifying ownership of the network and devices.
- Enables agency and technology independent network infrastructure and network services themselves (as desired).
- Reduces overall network traffic loads and any potentially required multi-jurisdictional interoperability issues.

Table 6-5: Telecommunication Alternative Comparison Matrix

Configuration Alternative	Qualitative Comparison Criteria						Overall
	Addresses Needs and Requirements	**Maintainability**	**Security**	**Redundancy**	**Flexibility and Expandability**	**Bandwidth Management**	
Alternative 1: Shared Ethernet (End-to-End) No Segmentation	◓ • Will be compatible with future in-kind IP-based systems deployed within MDOT Regions • Presents high potential risk levels for overall network efficiency • Optimal option to resolve potential budget constraints	◓ • Additional training will be required • Ethernet and digital knowledge base is more widespread • Maintaining Ethernet-based infrastructure will be simplified • Scheduled or unscheduled downtime could drastically impact each user and network	◓ • Ethernet is more susceptible to intrusion versus point-to-point networks • Data/video sharing (C2C or public) in an open format present additional inherent risks • Safeguards are available for system protection to achieve higher security levels	◓ • Ethernet versus physical redundancy can be increased, given inherent flexibility in terms of network topologies • Opportunities exist to migrate to a mesh network (full or partial)	◕ • Inherently seamless • System flexibility and expandability is network dependent	◓ • Inherently superior • Technology and agency dependent	◓
Alternative 2: Shared Ethernet (End-to-End) Virtual Segmentation	◕ • Will be compatible with future in-kind IP-based systems deployed with MDOT Regions • Presents medium potential risk levels for overall network efficiency • Improved use of backbone by establishing some form of boundaries	◓ • Additional training will be required • Ethernet and digital knowledge base is more widespread • Maintaining Ethernet-based infrastructure will be simplified • Scheduled or unscheduled downtime could drastically impact each user and network	◓ • Ethernet is more susceptible to intrusion versus point-to-point networks • Data/video sharing (C2C or public) in an open format present additional inherent risks • Safeguards are available for system protection to achieve higher security levels	◓ • Ethernet versus physical redundancy can be increased, given inherent flexibility in terms of network topologies • Opportunities exist to migrate to a mesh network (full or partial)	◕ • Inherently seamless • System flexibility and expandability is network dependent	◕ • Inherently superior • Technology dependent • Agency independent	◕
Alternative 3: Segmented Ethernet (End-to-End) Physical Segmentation	● • Will be compatible with future in-kind IP-based systems deployed with MDOT Regions • Superior use of backbone by defining separate networks • Seamlessly meets Signal integration requirements	◕ • Additional training will be required • Ethernet and digital knowledge base is more widespread • Maintaining Ethernet-based infrastructure will be simplified • Issues are network dependent	◓ • Ethernet is more susceptible to intrusion versus point-to-point networks • Data/video sharing (C2C or public) in an open format present additional inherent risks • Safeguards are available for system protection to achieve higher security levels	● • Ethernet versus physical redundancy can be increased, given inherent flexibility in terms of network topologies • Opportunities exist to migrate to a mesh network (full or partial) • Ethernet redundancy can be implemented per network/agency	● • Inherently seamless • System flexibility and expandability is based upon agency needs and requirements	● • Inherently superior • Technology and agency independent	●

Most Advantageous ● ◕ ◓ ◔ ○ ***Least Advantageous***

6.4 Recommended Telecommunications Network

In analyzing the different network configuration alternatives, it is apparent that Alternative 3 is not only the most effective overall, but addresses most if not all functional needs and requirements identified in previous sections. Furthermore, Alternative 3 continues to provide the opportunity of meeting near and long-term operational and system management objectives by enabling MDOT and the City of Grand Rapids to jointly develop a hybrid network.

For the full network build-out a hybrid (ring to partial mesh) topology is recommended and further described in the following sections. In addition the network design should be based upon a hierarchical model which establishes a form of hierarchy within the infrastructure and network appliances. A hierarchical network traditionally consists of layers such as core (backbone), distribution and access.

At a minimum it is recommended that Alternative 3 be applied for the core backbone communications network. However, in order to best utilize the existing MDOT and City of Grand Rapids ITS systems, the distribution and/or access layers may be a hybrid of the virtually and physically segmented network configurations (Alternatives 2 and 3 respectively) as needed.

With each alternative the impacts on existing operations and system maintenance will be significant. A carefully phased deployment plan should be developed to successfully migrate to an Ethernet solution while lessening operational impacts. Maintenance impacts will be significantly higher upfront due to the wholesale change in technology and techniques but will decrease over the long-term implementation of the network and infrastructure.

Capacity planning for the MDOT system build-out will be heavily dependent upon video requirements, more than any other device type. Therefore, the design must not only provide for the current planned number of cameras, transmitting full motion color video (MPEG-2 or MPEG-4), but also provide an infrastructure which allows installation of additional cameras when required and where desired. A robust and fully functional system must be designed and implemented in a “top-down” approach, which ensures maximum system flexibility, compatibility and enables systematic expansion without jeopardizing system performance or reliability. Furthermore, each network element must be carefully designed to ensure overall system integrity is maintained.

The following sub-sections further define the major elements of the recommended alternative.

6.4.1 Backbone Communications Network

A hierarchical build-out concept is based upon an architecture which implements short-haul or "distribution" links between field devices and nearby communication nodes or cabinet locations, medium-haul or "transport" links between communication nodes or cabinet locations and nearby hubs, and long-haul, or "backbone", links between communication hubs and the TMC. The hubs and nodes are the aggregation points where data from many device types is gathered and combined onto more efficient wideband media for transmission upstream to the TOC. This approach reduces the quantity and expense of fibers and associated communication equipment required for a full network build-out.

Table 6-2 illustrates the total number of anticipated ITS devices to be deployed long-term within the Region while Table 6-3 demonstrates that the anticipated (worst case using MPEG-2) bandwidth for the total devices will be just over 1 Gbps. Due to the inherent nature of communication circuits, Ethernet overhead and future expansion needs a network should never be fully loaded to its maximum capacity. Therefore the network build-out of the communications backbone must be able to accommodate 50% more capacity than the identified threshold to adequately handle the full and long-term network build-out plan for the Region.

However, due to the drastic difference in existing versus full build-out device quantities it is anticipated that the long-term network build-out will be ten or more years away, and the technology industry traditionally has been known to change before communication elements are even deployed. Therefore, the full 2+ Gbps backbone may not be required for many years and careful consideration must be taken during future design stages to completely understand the expansion needs and requirements of the user and system. Additionally, once the physical network architecture and communications medium is established and in place the only modification required within the network to “up-size” system capacity with be the actual edge devices or modules within the edge devices themselves (dependent upon selected equipment and configuration of course).

Figures 6-4 through 6-10 illustrate a recommended migration path for the MDOT backbone communications network in both a geographical representation and a schematic topology, based on existing and planned conduit locations and the assessment of future needs. The migration is proposed to take place in three major phases:

<u>Phase 1:</u>

- Implementation of a partial mesh Ethernet backbone over existing or proposed fiber-optic cable in parallel with existing system
- Integration of existing system(s) directly to the MDOT backbone
- Phased migration of existing field devices directly to nearby communication hubs or node using a combination of wired and wireless connections

<u>Phase 2:</u>

- Expansion of the partial mesh Ethernet backbone along I-96 between I-196 and US-131 to establish Ethernet redundancy by providing an additional communications pathway to the WMTMC
- MDOT’s signal system migration, if desired, from the City of Grand Rapids network, either from existing configuration or Ethernet-based (if City has already performed their migration before this phase).

<u>Phase 3:</u>

- Expansion of the partial mesh Ethernet backbone in the existing conduit along M-6 between I-96 and I-196
- Introduction of new Nodes as necessary to accommodate expansion/integration of devices along identified priority corridors
- Introduction of new nodes or wireless communications towers as necessary to accommodate long-haul interconnections to other Regions

It is recognized that the City of Grand Rapids may share the proposed backbone location and general topology as a means of leveraging shared regional conduit infrastructure. However, based on the recommended network configuration, the City would operate a parallel backbone on dedicated fibers and using dedicated network appliances separate from the MDOT network. As such, the capacity requirements discussed are based on MDOT systems and inter-agency requirements, and do not include the existing or future load requirements for the City of Grand Rapids.

Figure 6-4: Existing and Planned Multi-Agency Communication Network

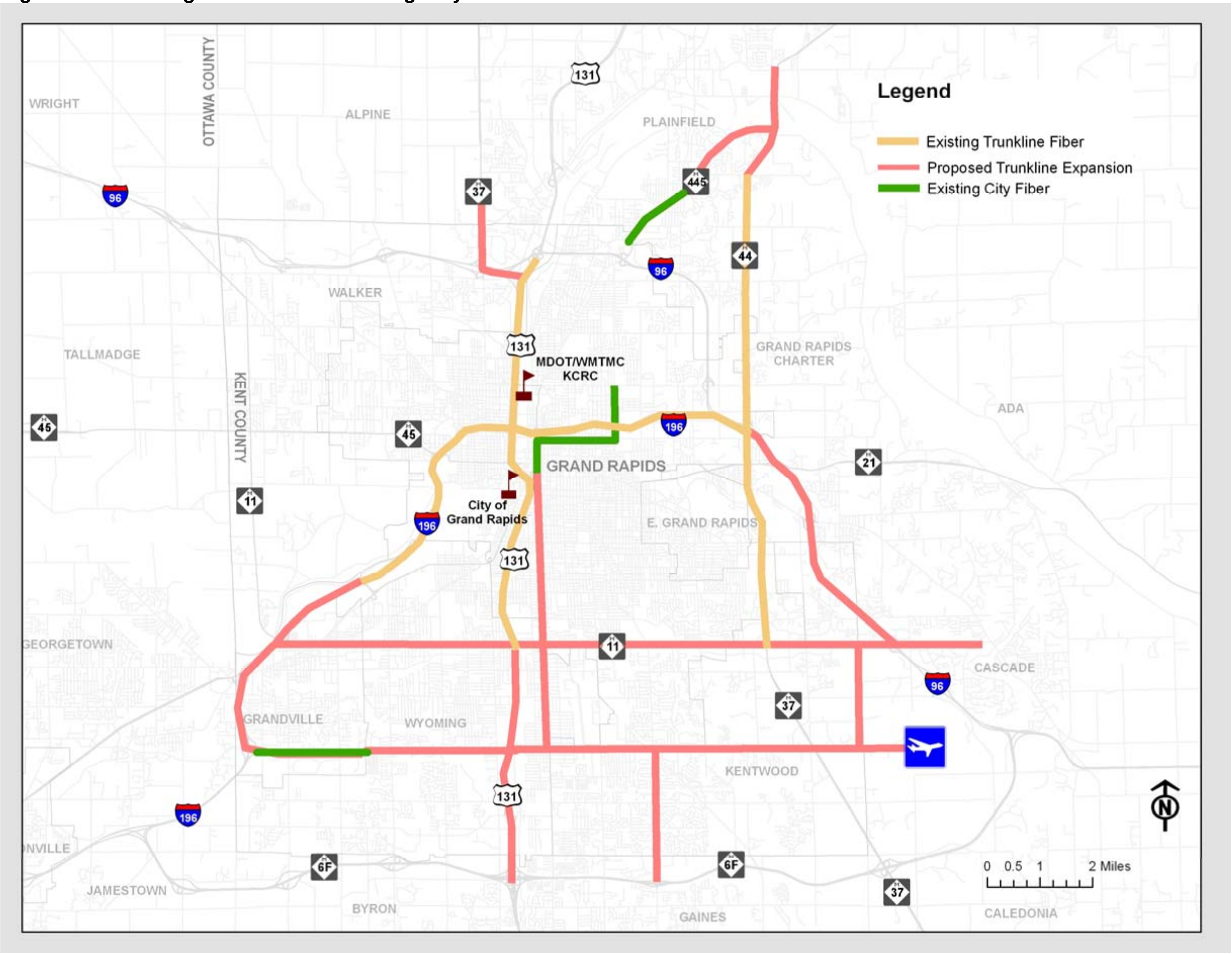


Figure 6-5: Recommended Backbone Communications Network (Phase 1)

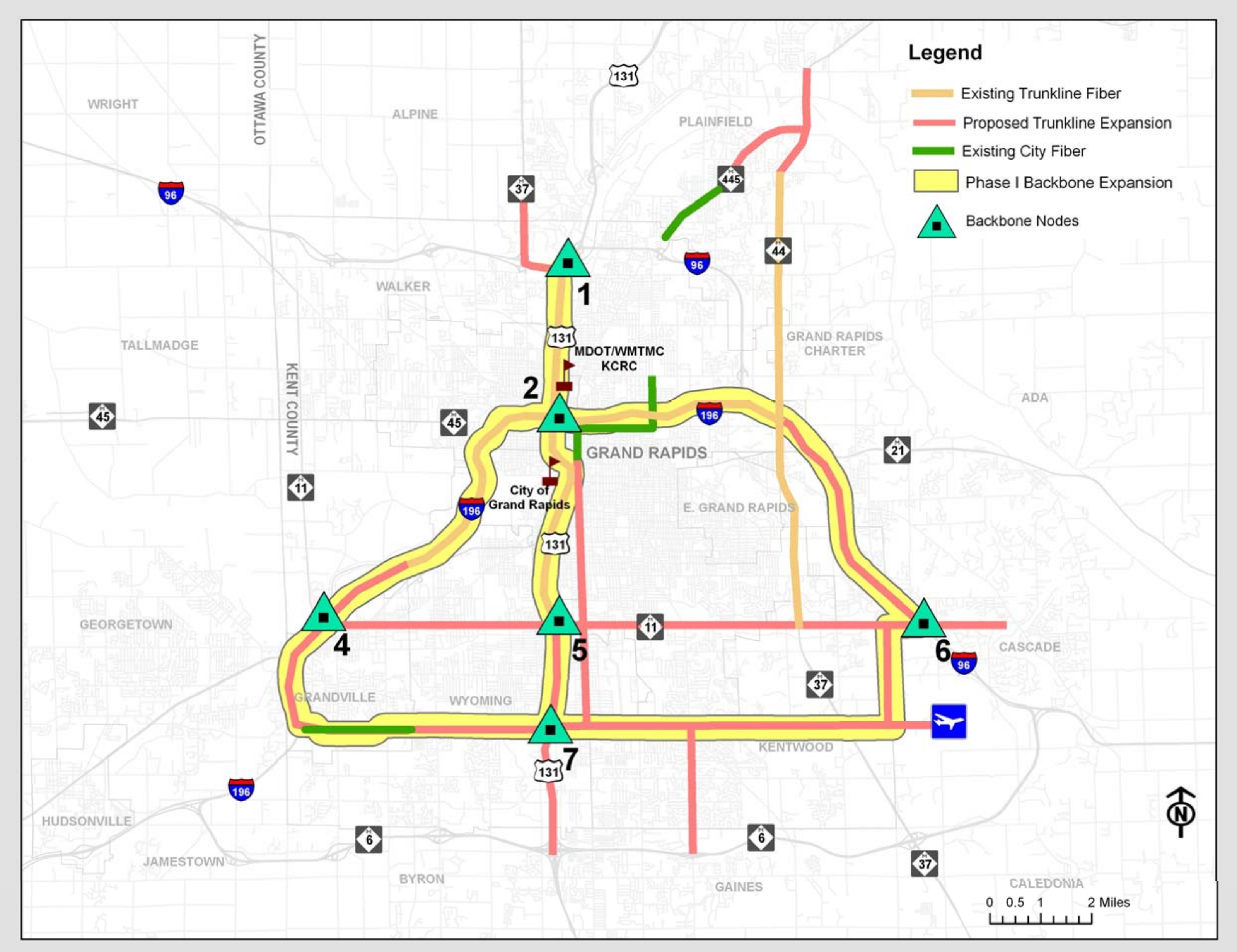


Figure 6-6: Recommended Network Topology (Phase 1)

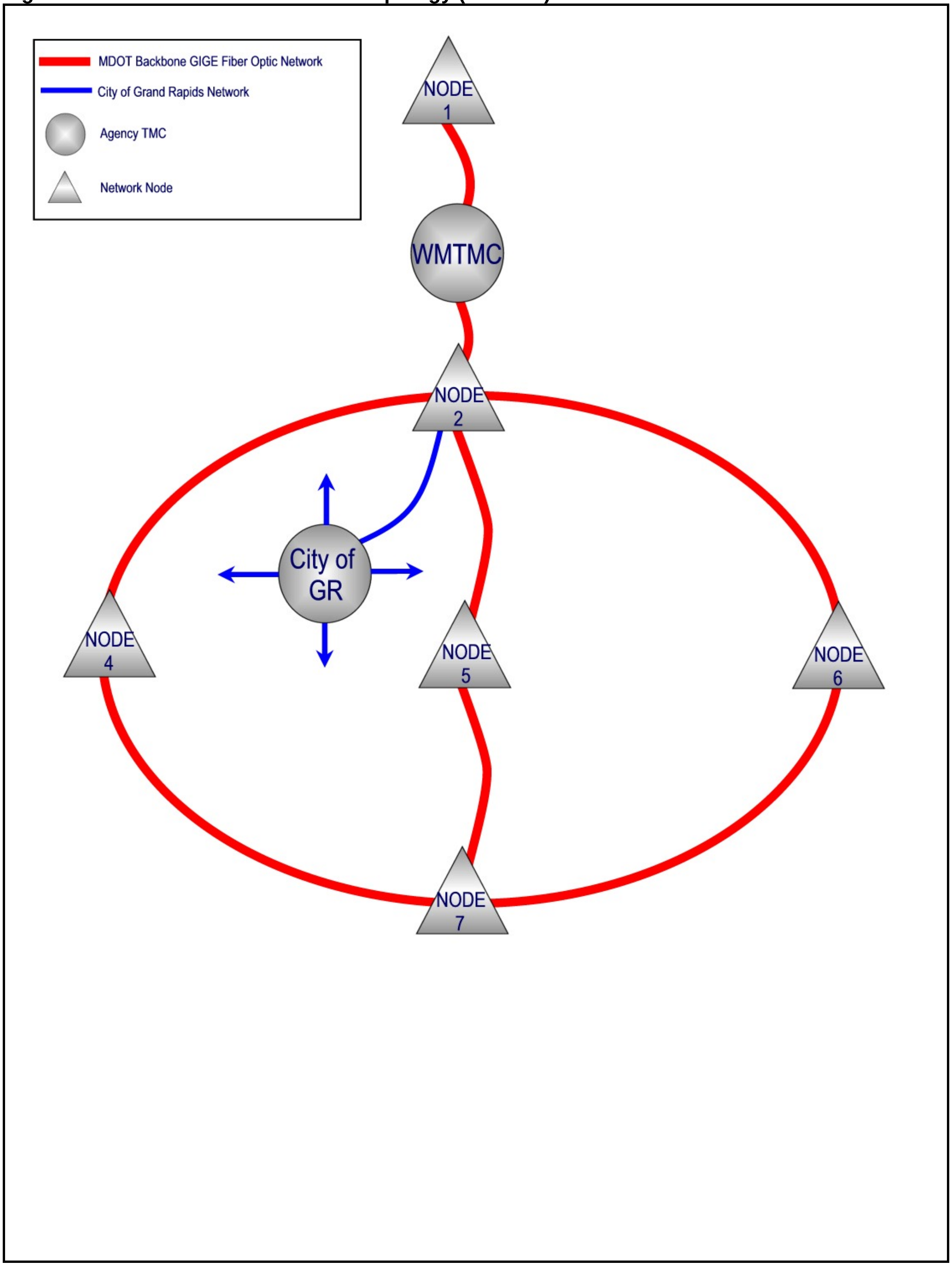


Figure 6-7: Recommended Backbone Communications Network (Phase 2)

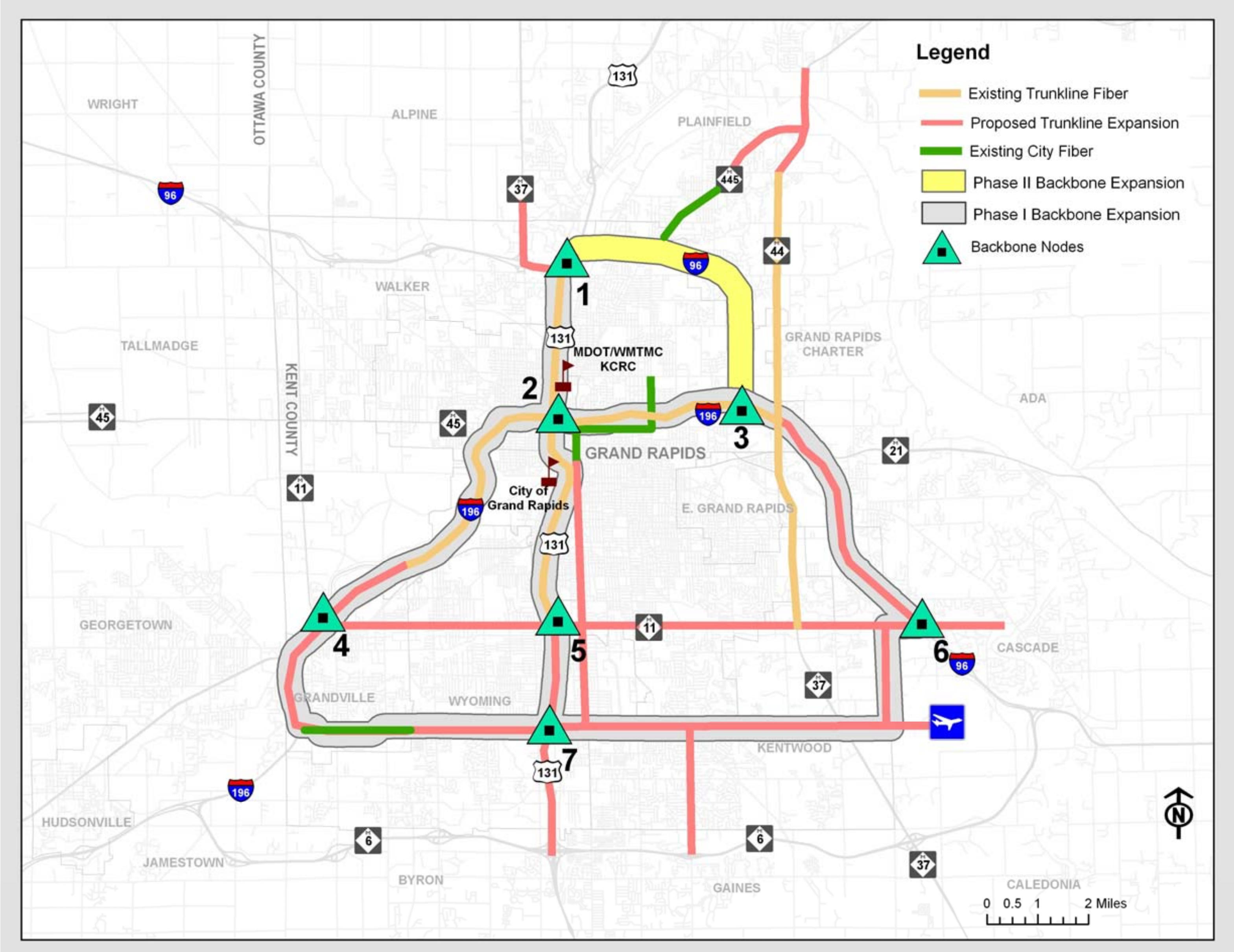


Figure 6-8: Recommended Network Topology (Phase 2)

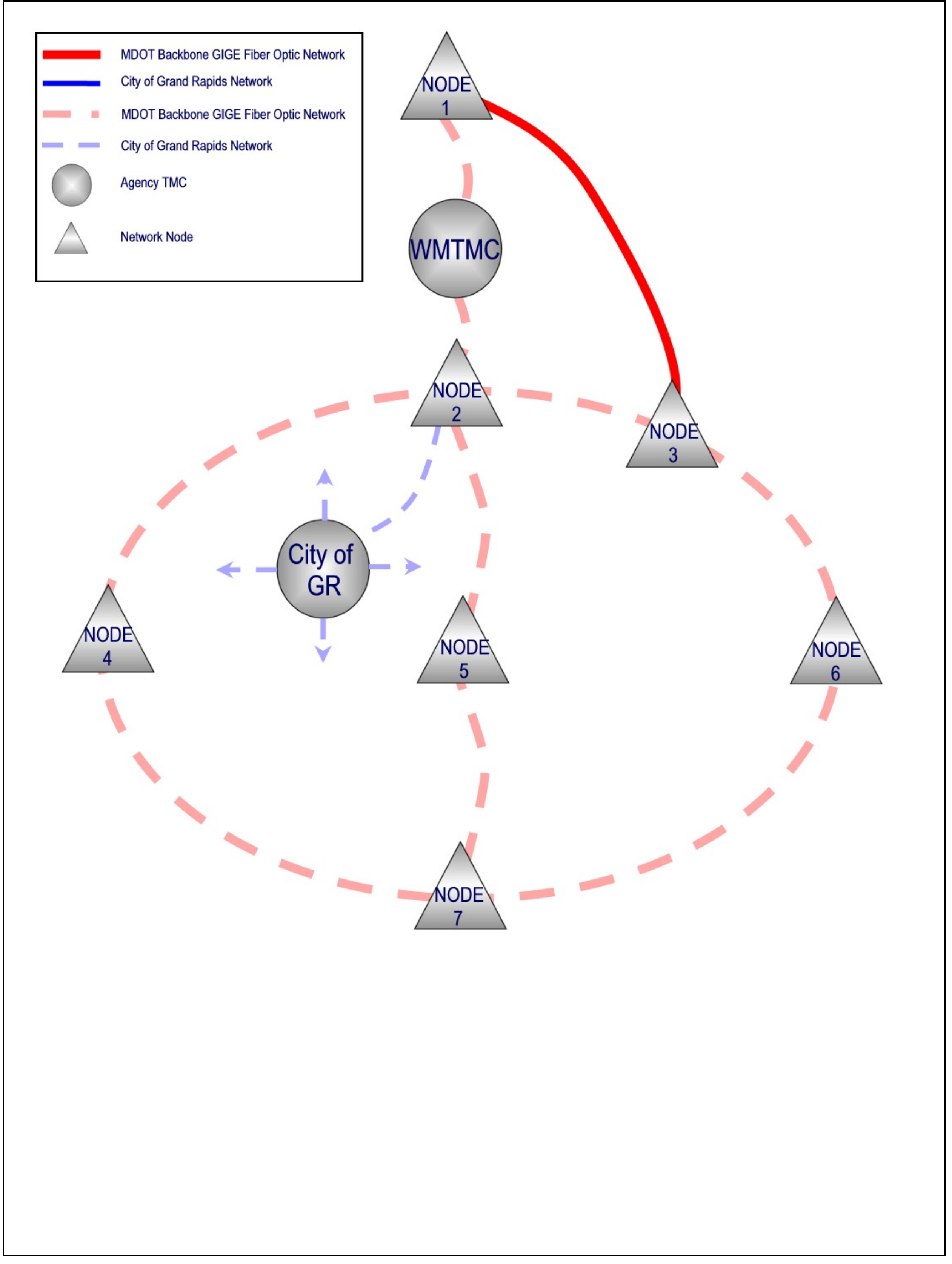


Figure 6-9: Recommended Backbone Communications Network (Phase 3)

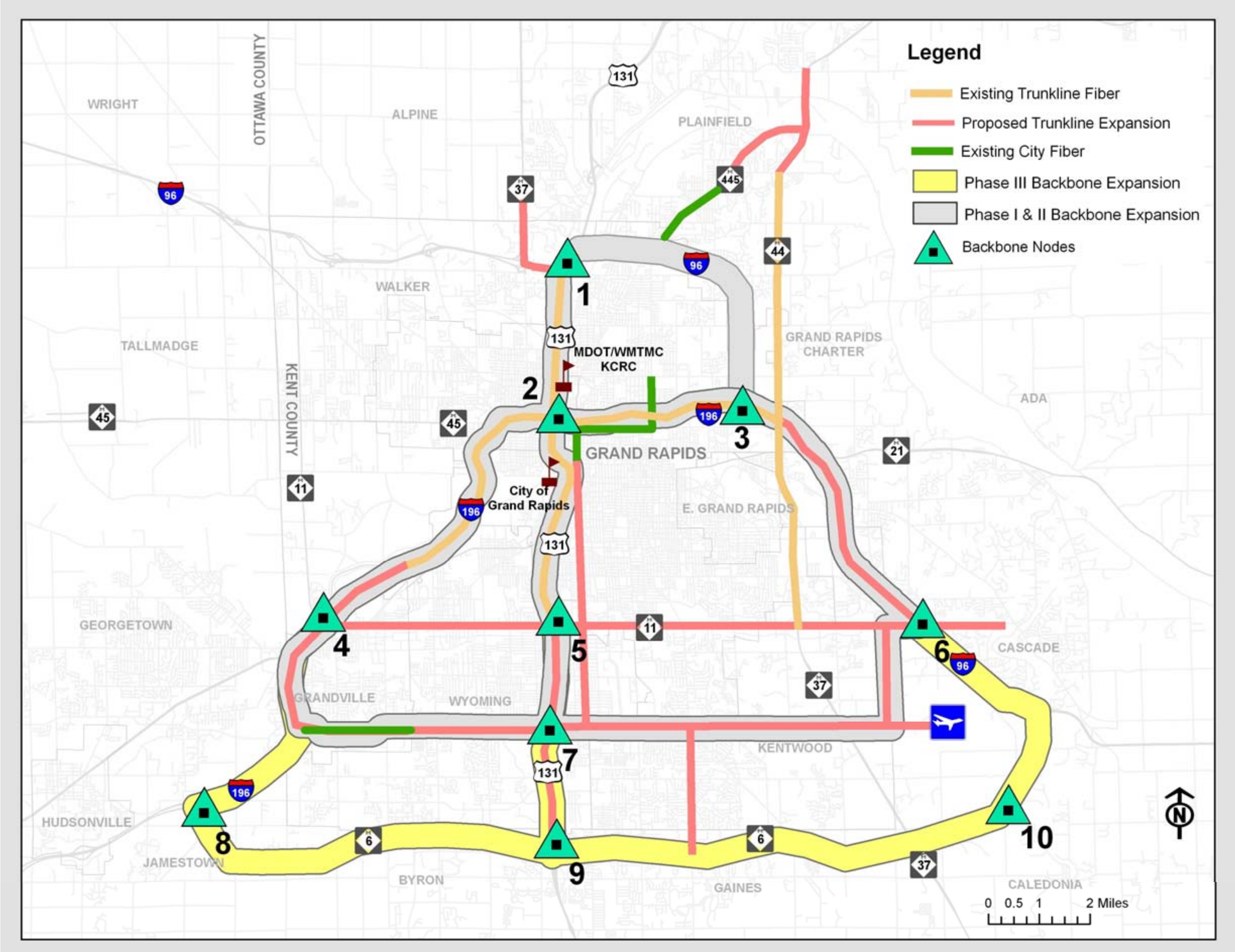
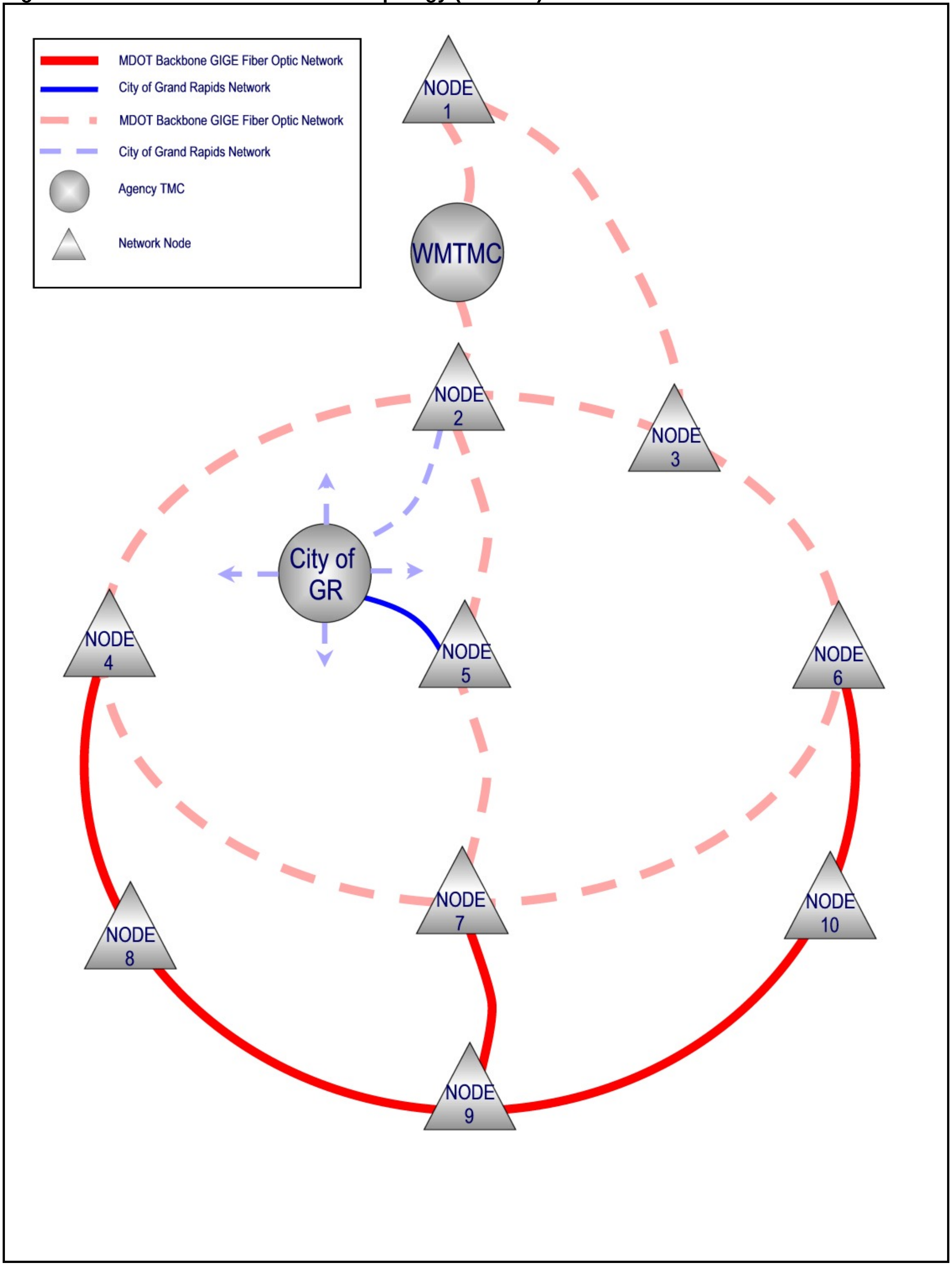


Figure 6-10: Recommended Network Topology (Phase 3)



6.4.2 Distribution Network

End-to-end field device connectivity commonly requires the use of one or more distribution mediums (wired or wireless) to enable device deployments into the Region's furthest or most difficult points in the most cost effective manner. One of the advantages of a gigabit-Ethernet-based concept is its ability to deploy networks in stages for a more gradual and phased migration approach to achieve the optimized networking plan.

The current MDOT and City of Grand Rapids ITS networks consist almost entirely of fiber-optic communications. While fiber-optics generally represent the highest degree of capacity and reliability, installation of fiber-optic cable, particularly in-ground, is costly and can be complex in circumstances where conduit is retrofit along a corridor. Furthermore, many of the applications utilized within the network, including traffic signal control, DMSs and vehicle detection, require transmission only of simple data packets which require very little network capacity.

Wireless communication presents a viable alternative and can be deployed as short-haul or "distribution" links for connectivity to the core backbone or transport layer at a reduced capacity and associated cost. MDOT has significant experience with wireless technologies for transmission of both data and video in the Metro Region ITS network, as well as for signal system communication at locations throughout the state. Advances in wireless technologies have greatly improved reliability, capacity and security, while maintaining a low cost relative to wired technologies.

The most practical approach for implementing this type of concept would be to deploy the core routing backbone (based on existing and planned fiber deployments) and adding wireless supporting technology segments to expand network coverage as desired. Moreover, the Federal Communications Commission (FCC) has allocated wireless frequency bands for the public safety sector, which provides additional benefits over its wireless counterparts as discussed in the previous sections. Additionally licensed wireless frequency bands provide similar type of benefits, although at higher associated costs versus the public safety bands.

Once a defined network backbone has been established, it is recommended that MDOT fully consider both fiber-optic and wireless options during expansion planning efforts.

6.4.3 Long-Haul Interconnection

As identified in the needs and requirements section MDOT has expressed the desire to establish capabilities within the network plan for enhanced center-to-center (C2C) capabilities, including potential long-haul type interconnections to Lansing. Furthermore, while the need for a dedicated communications network linkage to areas of the Grand Region outside of the immediate Grand Rapids urban area was not identified, the distances that must be bridged to provide this future connectivity, should significant ITS expansion warrant it, would make dedicated wireline communications cost-prohibitive.

The network concept and long-term plan anticipate achieving long-haul interconnections via wireless communication technologies (typically licensed microwave), leveraging the existing Michigan Public Safety Communication System (MPSCS) tower infrastructure and partnerships already established, along with potentially new MDOT communications tower locations, ideally co-located with network nodes on the backbone. The MPSCS maintains towers throughout the state that could house dedicated MDOT radios to facilitate high-capacity long-haul communications between distant points. The MPSCS tower infrastructure within the Grand

Region is depicted in Figure 6-11. These types of interconnections and entry points into the network must be further evaluated and determined during the detailed design stages by evaluating capacity requirements and conducting wireless path analysis in order to identify potential new tower locations.

6.4.4 Signal System Integration

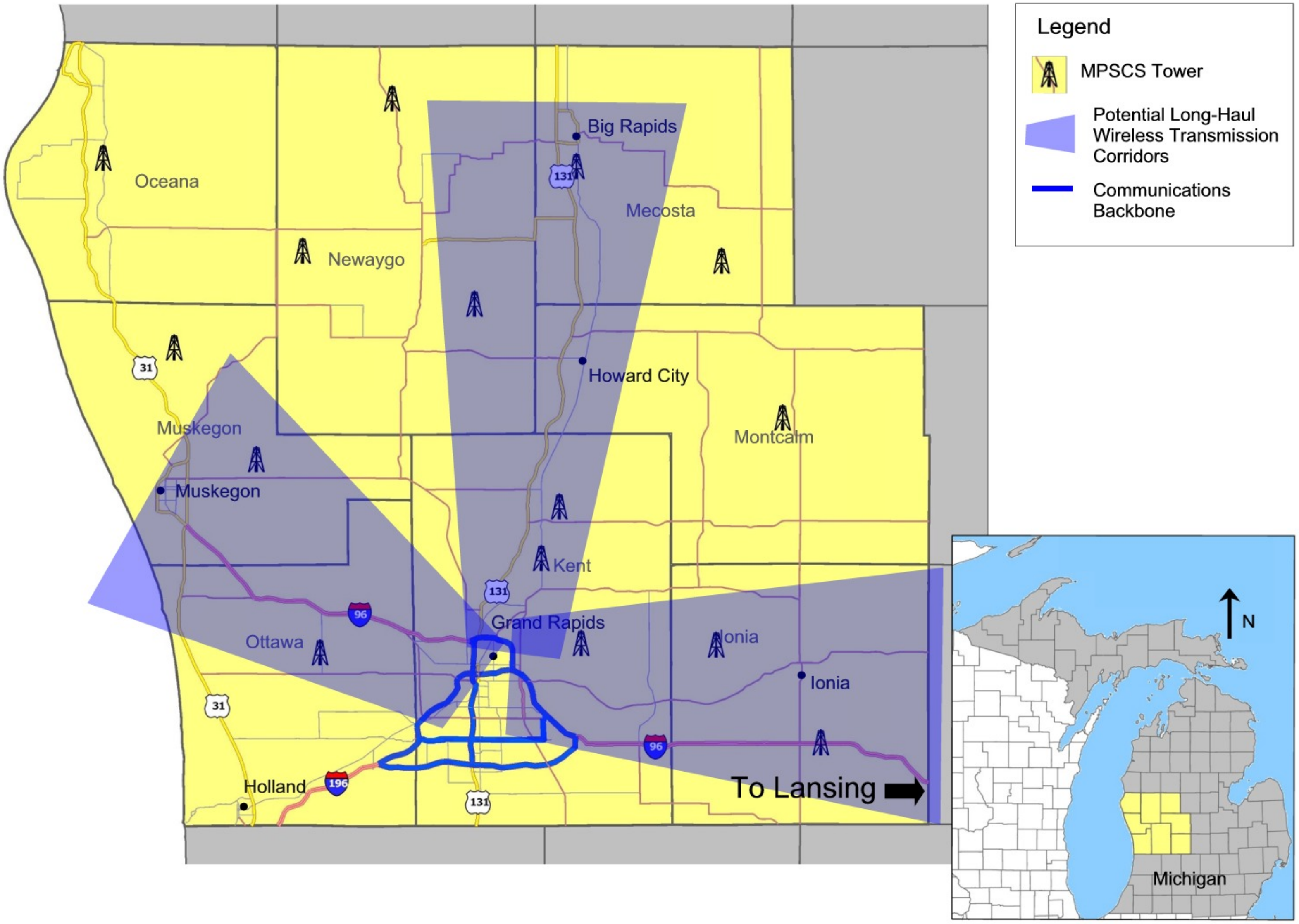
MDOT's existing signal system consists of two different communication architectures, the first being traffic signals which are directly connected (via fiber-optic or spread spectrum wireless) to the City of Grand Rapids central signal system, and the second being POTS-based (plain old telephone service) dial-up service closed loop systems which can be managed generally from any location with an analog phone circuit and appropriate central management software. The POTS-based traffic signals in the Grand Region are generally managed by the local counties and/or MDOT's Lansing Signals Unit. The traffic signals which head-end into the City of Grand Rapids TMC are accessible to MDOT at the WMTMC.

Several options exist for MDOT to leverage the communications infrastructure within the network to improve communications with existing closed-loop signal systems, to expand current systems, or to migrate to a central signal control system. The potential for signal system integration hinges on two elements: Communications media and equipment, and migration options.

Given that MDOT's main form of serial communication to their intersections is direct connect or POTS-based, there is a limitation on the operations staff's ability to actively manage the intersections in the field relative to the industry as a whole. MDOT needs to evaluate the specific operational needs in order to determine their communication requirements. The types of issues that MDOT should evaluate are:

- Controller Hardware Issues
  - New controllers have more capabilities that require specific communications capability to fully utilize
  - Ability or need to replace/upgrade field equipment (e.g., cabinets, conflict monitors, etc)
  - Desire to "buy smart" – more than one vendor's hardware or model
- Operational Issues
  - Desire to use open interface standards (NTCIP)
  - Continuous monitoring need for alarms
  - Timing plan management for route diversions, emergency evacuations, etc.
- Advance Operational Strategies
  - Implementation of adaptive control operations
  - Transit priority and preemption
  - Center-to-center communications with adjacent jurisdictions to share operation of traffic signals as well as ITS devices within the corridors of interest
  - Share operational characteristics with adjacent jurisdictions
  - Shared communications with other ITS devices (CCTV, VMS, Detectors)

Figure 6-11: MPSCS Communication Tower Locations



Signal System Migration

Migration to a new communication architecture will require MDOT to work closely with the signal controller vendors. The existing controllers are supplied with serial communication interface compatible with fiber-optic or dial-up modems. Migration will require a plan on the transition from equipment and operations. The desire to share the communication backbone with other ITS devices indicates a need for high bandwidth, network segmentation and addressing capabilities. The solution will fall into a category that can support Ethernet-based standards. The communications infrastructure will require a higher bandwidth solution in order to support the IP-based networking and NTCIP-based protocols. The ultimate bandwidth of the communications backbone will determine networking design, controller addressing (controller per channel, IP sub-netting, security, etc.).

The traffic signal system migration is recommended in two segments, which could be implemented in parallel with any of the communication network phases described above. Listed below are the identified segments:

- Potential migration of direct connect traffic signals to the MDOT network (as is feasible and efficient)
- Migration of POTS-based signals from nearby Counties

Both of these traffic signal segments will require either a replacement or upgrade of the controllers deployed in the field cabinets. The available path involves two basic options:

- Upgrade the signal controllers to a more modern version that has Ethernet capabilities built into the unit
- Add a communication interface device to convert the communication protocol from serial to Ethernet allowing the existing controllers to remain functional

If performed, the migration of traffic signals directly to the MDOT network will be rather simple in the terms of establishing network connectivity to the new MDOT communications network. These signals are already located within the metropolitan area of Grand Rapids and therefore are in close proximity to nearby conduit and consequently the new communications network build-out underway and planned. In addition to requiring the above mentioned controller replacement or upgrade, a phased network connection approach to each corridor should be utilized for the full traffic signal system migration. Each corridor must be further evaluated during the detailed design stages.

Listed below are the communication options available for migration of the POTS-based traffic signal segments from the currently utilized communication architecture. Additionally, MDOT does not have to undertake the upgrade and migration of all the Counties or even whole Counties at one time. Each County or portions of the County can be phased into the new communications network build-out over time. Each option must be further evaluated during the detailed design stages. The backbone will be one of two basic types:

- Hardwire – Most signal systems are build on a hardwire backbone. It allows for guaranteed bandwidth, installation options (agency implemented/owned, leased, shared resources), and a high degree of security. It is typically expensive to install a hardwire backbone and leasing offers recurring costs.

- Wireless – Typically wireless communications has been used in the signal industry in support of filling in gaps in the hardwire backbone to reach locations on a temporary or small range basis. Issues typically arise from background interference, lack of reliable service, difficulty in maintenance, and security concerns. Properly designed and integrated, wireless communications can provide the necessary bandwidth and functionality as a hardwired solution.
- Hybrid Solution – A reasonable implementation may involve a combination of both hardwire and wireless communications.

The Ethernet backbone will provide capability of interconnecting signals to exchange data for advanced traffic control strategies such as adaptive control (e.g., sharing detector data, signal timing parameters, etc.).

Given that MDOT is strongly considering moving towards an ACTRA central software package, the need for a communications backbone becomes very important. Selection of wireless communication media will require coordination with the central system provider to ensure the central software can support the potential latency, interruption of service, and bandwidth associated with the communications backbone and the controller's protocol.
Design issues to consider:

- What are the best communication options for linking the MDOT infrastructure to the signals (i.e., one link to a master location, with "interconnect" from there, or direct links between a node and every signal)?
- How can the current closed-loop structure be maintained (if that is desired) but still using MDOT infrastructure for communication?

Many systems have both closed loop and direct connect solutions in the same central system. It is done with either a master driver or GUI launch of vendor software.

6.5 Migration Strategy

The recommendation to upgrade the MDOT communications infrastructure to an Ethernet/IP-based network comes with a number of considerations in terms of how to migrate the network from the existing technology and techniques, while maintaining the desired level of network service during the implementation and migration periods. This section describes the variety of options available for MDOT to achieve its objective of a successful migration of the existing infrastructure, including:

- Some of the requirements, assumptions, and constraints that exist with an Ethernet/IP-based system implementation
- Utilizing a phased implementation and migration approach to achieve the full network build-out
- A long range deployment strategy for migrating the existing communications infrastructure and systems to the preferred alternative

The deployment strategy revolves around creating a regional-based Gigabit-Ethernet communications network utilizing existing infrastructure and planned build-out communications. Fiber optic communications cable is recommended to provide the necessary system capacity or to fill the gaps and/or add a level of path redundancy.

6.5.1 Requirements, Assumptions, Constraints

A key element in any system implementation is the establishment of requirements and assumptions, and an understanding of known constraints to be expected in the process. Some of the key factors that influence the technology migration to the recommended alternative are as follows:

- Establishment of a fiber backbone that would achieve the following requirements:
    - High bandwidth with 1 Gbps (minimum) of aggregate capacity
    - Efficient utilization of bandwidth
    - High Quality of Service
    - End-to-end network management and maintenance
    - Multicasting capabilities for efficient video sharing
    - Scalability to accept future expansion of backhaul infrastructure and accommodate additional hubs and nodes
    - Intelligent network management capabilities
    - Enhanced system restoration and convergence capabilities
- A transition with minimal operational disruption
- An approach towards implementation with functional distribution of migration activities
- Cost effectiveness in deployment, operations, and maintenance

During the design process for upgrade of system elements and technologies, it is recommended that MDOT revisit these basic requirements and establish others to help guide the system design and migration process.

6.5.2 Phased Approach

Deploying fiber-optic cable in phases and establishing communications between strategically located nodes and operation facilities will provide connectivity in the most effective way possible. The phases are broken down in logical order (Phases 1, 2 and 3). Once the core backbone is established with single mode fiber-optic cable under Phase 1, the remaining phases for system expansion and redundancy can be deployed as time and budget permit. Because of the sheer size, complexity and cost of erecting longitudinal communications on a regional level, the communications system must be developed in stages. The staged implementation is based on priority areas, project deployment and building the communications to meet the near and long term regional needs.

The deployment strategy includes identification of projects and activities for the short term (less than three years), medium term (3 to 5 years) and the long term (beyond 5 years). Alternative strategies were analyzed for the long-term build-out of the MDOT fiber-optic network. Based on various funding scenarios, implementing a fully-functional system over a longer horizon is recommended, as such an approach allows for meeting all of the project's goals for:

- Functionality: Provides the basic infrastructure for incident management, traffic management, traveler information, and traffic data collection

- Coverage: Provides geographical coverage of the region with an adequate density of field equipment

- Construction cost: This alternative has the highest capital cost for developing regional communications, however provides long-term cost-savings throughout the infrastructure life cycle

- Communications: Provides a network core, which will provide the bandwidth to support full system build-out, regional needs and provides redundancy for back-up operations

- Expandability: Optimizes the potential expandability of regional stakeholders

The recommendation to upgrade the MDOT communications network to an Ethernet/IP-based network as previously discussed comes with a number of considerations in terms of how to migrate the network from the existing point-to-point technology, while maintaining the desired level of service during the migration period.

6.5.3 Migration Process, Planning, and Paths

While there are several routes towards migration from the existing point-to-point infrastructure to an Ethernet network, the migration methods contained in this document have been developed around an all-digital solution which encompasses the following components:

- Ethernet as the backbone medium of communications
- Migration of edge device communications
- Ethernet aggregation and transport of video signals from camera sites and low-speed communication devices over the Ethernet backbone to the WMTMC

Migration planning is not a onetime event but rather a continuous engineering process for improvement that should be occurring constantly within a system's life cycle. Technology is advancing at a rate that is outpacing deployment; therefore, by the time it is deployed another technology has taken its place. This is the main reason that a continuous engineering process needs to assess the technological advancements as they pertain to the department's systematic goals and to determine which ones will benefit the department. Not all technological advancements will necessarily fit into the infrastructure as it is designed; therefore, determining if it is a value added system change worth implementing into the design is necessary.

Migrating between different versions of a component or device introduces the potential to disrupt existing operations. Besides maintaining operational efficiency, MDOT must also manage other risks that may occur as systems are migrated, including:

- Maintaining operational performance and integrity
- Meeting user and public expectations
- Assuring that systems are well planned and designed before they are migrated
- As equipment becomes obsolete over time, developing and prioritizing which obsolete equipment will be replaced first
- Start the migration in an "inside-out" versus "outside-in" approach enables more value quicker during the system build-out and expansion
- Build a parallel communication network and migrate existing devices after system is tested
- Developing a test plan and procedures prior to implementing the migration plan
- Phasing in the migration such that if problems arise, there is a fall back to continue operations while the problem is investigated and corrected

- Managing costs and schedules

This system has three (3) elements that need to be considered to develop a migration plan:

- Control Center
  - Hardware – The migration/upgrade of the communication system may not negatively impact the operations of the software, but still may require replacement of obsolete equipment in the control center that are part of the communication hardware infrastructure. For example, while codec replacement will not affect the software, it will affect the availability of some of the video from the field.
  - Software – Minor changes/upgrade in the communication system software should not have a negative effect on the existing vendor based software, but may include new functionality that allows the operators a more efficient method to perform certain tasks or fault isolation.
- Communication System – The existing point-to-point equipment in the communications system will be phased out or decommissioned when the new network becomes available.
- Field Equipment – The existing field equipment may have a manufacture interface kit or provide a direct connection to the new technology selected, thus reducing the complexity of the change and providing a seamless transition to the new technology or interface.

MDOT's existing communication system is predominately point-to-point, analog-based and does not have a defined core or transport layer and therefore inherently does not provide an upgradeable path through the existing communications system. Although this may seem negative, it is actuality a considerably important feature and benefit. This being the case, MDOT can implement and build-out the Ethernet network in parallel with the existing systems being fully functional and not impact the system operations until the migration phases.

The existing system's migration phases do not have to present any major impacts either because once the new Ethernet network is in place and tested the existing devices can be migrated on a one-by-one basis, thereby drastically reducing overall impact to the system and users. Listed below are some of the additional advantages and features of this method:

- Provides the opportunity to test and validate device types as they are integrated into the new network to maintain system integrity
- Provides a solid fall-back plan and concept if any major issues are encountered during transition(s)
- Provides leisurely system migration and upgrade to reduce overall impacts and budget constraints
- Lastly, it provides the ability to troubleshoot single devices versus sub-system or system level issues

APPENDIX A
LIST OF ACRONYMS

ACTRA	Traffic management software package produced by Siemens
ADM	Add/Drop Multiplexer
AM	Amplitude Modulation
ATIS	Advanced Traveler Information System
ATMS	Advanced Traffic Management System
C2F	Center-to-field
C2C	Center-to-center
CCTV	Closed-Circuit Television
CMS	Changeable Message Sign
CoS	Class of Service
EMS	Element Management System
FCC	Federal Communications Commission
FDD	Frequency Division Duplex
FHSS	Frequency Hopping Spread Spectrum
FHWA	Federal Highway Administration
FSSS	Fast Serving Station Switching
Gbps	Gigabits per second
Gig-E	Gigabit Ethernet
GHz	Gigahertz
GFP	Generic Framing Procedure
GUI	Graphical User Interface
GVMC	Grand Valley Metro Council
HAR	Highway Advisory Radio
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol
ITS	Intelligent Transportation System
KCRC	Kent County Road Commission
LAN	Local Area Network
Mbps	Megabits per second
MDOT	Michigan Department of Transportation
MPEG	Moving Pictures Experts Group (Video Format)
MPLS	Multi-Protocol Label Switching
NMS	Network Management System
NTCIP	National Transportation for ITS Communications Protocol
NTSC	National Television System Committee
OA&M	Operations, Administration, and Maintenance
OCRC	Ottawa County Road Commission
OSPF	Open Shortest Path First
POTS	Plain Old Telephone Service
PMP	Point to Multipoint
PP	Point to Point
PTR	Permanent Traffic Recorder
PTZ	Pan Tilt Zoom
RF	Radio Frequency
ROI	Return on Investment
RTMS	Remote Traffic Microwave Sensor
RWIS	Road Weather Information Station
QoS	Quality of Service
SAN	Storage Area Network
SCADA	Supervisory Control and Data Acquisition

SDH	Synchronous Digital Hierarchy
SDP	Strategic Deployment Plan
SHF	Super High Frequency
SONET	Synchronous Optical Network
SSMA	Spread Spectrum Multiple Access
SSR	Spread Spectrum Radio
TDD	Time-Division Duplex
TDM	Time-Division Multiplexing
TE	Telecommunication Traffic Engineering
TMC	Traffic Management Center
TSC	Transportation Service Center
UHF	Ultra High Frequency
VC	Virtual Circuit
VII	Vehicle Infrastructure Integration
VMS	Variable Message Sign
VLAN	Virtual Local Area Network
VPN	Virtual Private Network
VSLS	Variable Speed Limit Sign
WAN	Wide-Area Network
WIM	Weigh-in-Motion
WMTMC	Western Michigan Traffic Management Center